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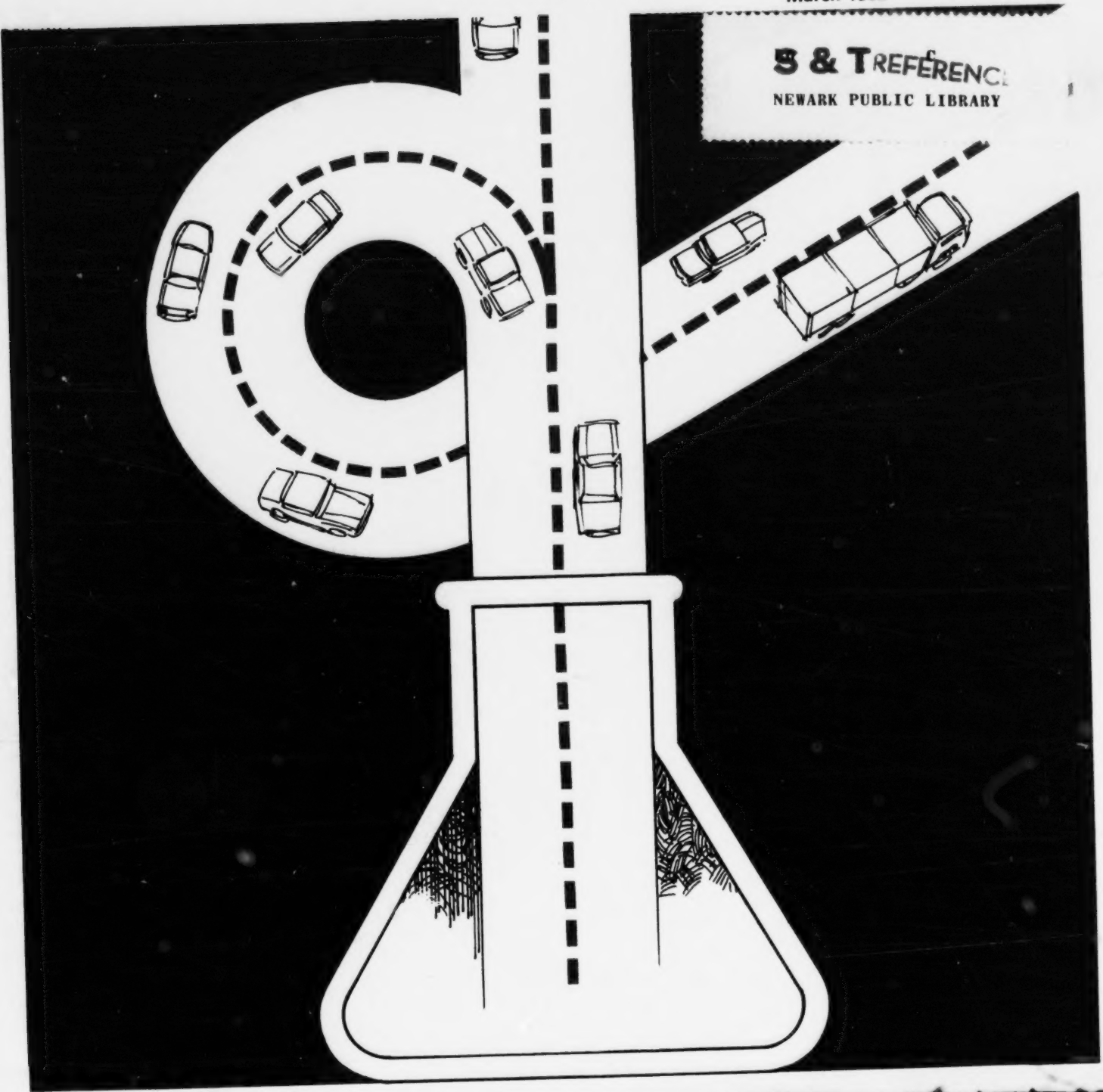

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March 1982 Vol. 45, No. 4

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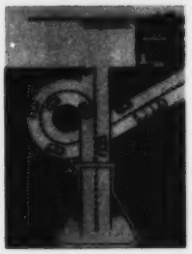

COVER:
FHWA's Technology Transfer Program concentrates on bridging research, development, and application.

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Federal Highway Administration Technology Transfer Program—A Historical Perspective

by
Milton P. Criswell

This issue of *Public Roads* is devoted to technology transfer. This article introduces the Technology Transfer Program, and subsequent articles describe the role of the FHWA field offices, Implementation Division, Demonstration Projects Program, National Highway Institute, and Experimental Projects Program in disseminating technology for application.

Introduction

Technology transfer, the process by which existing research knowledge and new technology are transferred operationally into useful processes, products, or programs that fulfill actual or potential public or private needs, (*1*)[1] can best be expressed in three words: *Get It Done*. The idea of transferring technology to economically or socially improve life is a sound one. However, people and institutions resist change so there is no easy way to insure that better ideas will be tried or that better techniques will be used. Highway transportation literature indicates that from the early days there was a continuing attempt to develop processes for shortening the time between research discovery and application. A sketchy history will be described to illustrate that research and technology transfer played a substantial and

[1] Italic numbers in parentheses identify references on page 137.

significant role in the development of the U.S. highway transportation system. (*2*)

1775–World War I

Early turnpikes in the United States were paved and maintained according to the recommendations of J. P. M. Tresaguet, Director General of the French roads from 1775 to 1785. After 1820 the ideas of the Scotsman John L. McAdam dominated American roadbuilding to the late 1880's. The 1890's launched the "good roads" movement. A key technical element of this movement was the publication and dissemination of educational articles on the principles of good roadbuilding and the economic effects of all-weather roads. Pictures were used to illustrate good and poor roads.

Highway research and scientific roadbuilding actually began with the establishment of the Office of Road Inquiry (ORI) in the U.S. Department of Agriculture in 1893. With the creation of this Office, whose primary mission was to investigate the best methods of roadmaking and to assist in disseminating this information, a formal, organized research program began. (*3*)

In 1897 as the program expanded, ORI built the first object lesson road project (fig. 1) at a cost of $321 to demonstrate the practical side of roadbuilding. Experimental construction, demonstration projects, and personalized technical assistance were applied successfully to transfer new technology involving materials such as coal tar, petroleum, local earth, and sand-clay materials.

Before 1917, the main problems for highway engineers were financial, not technological. The feeling of technological well-being came to an abrupt end in the spring of 1918 with the widespread failure of roads under heavy truck loads. Roads built before World War I were narrow and thin but adequate for automobiles and farm vehicles. The need for major research programs became evident after these road failures, and the Bureau of Public Roads (BPR, the forerunner of the Federal Highway Administration) provided national leadership in initiating and carrying forward a program of research in highway design and construction. In-house activities were expanded and cooperative research agreements were made with State highway or transportation departments and universities.

Figure 1.—Object Lesson Road.

1920–1960

The BPR's research program was responsible for solving the major technical problems impacting the highway transportation system from the 1920's through the 1950's. The research was problem oriented, addressing a range of subjects such as pavements, soils, aggregates, coating materials, design and location, capacity, economic life, and safety user costs. It was understood that useable research results would be implemented. These early technology transfer efforts involved technical assistance, publications, dissemination programs, experimental projects, demonstration projects, and considerable personal contact between those providing and those receiving the information. These same ingredients are found in the highly successful technology transfer programs of today.

With the beginning of construction of the Interstate System and the substantial increase in automobiles and trucks during the 1950's, new problems and issues, such as urban congestion, highway safety, and reducing highway construction and maintenance costs, came into focus. A full range of expanded research and development programs was developed to address these problems and issues.

1960's

In the 1960's several significant events led to dramatic changes in the concept and activity of research, development, and technology transfer in the highway program. In 1961 an independent Office of Research and Development was established in BPR with equal rank to Planning, Engineering,

Operations, and other major elements of BPR.

The Federal-aid Highway Act of 1962 required 1.5 percent of highway Federal-aid funds be used for planning and research beginning in Fiscal Year 1964. This requirement eliminated the option of using this money for construction and so insured the strength and vitality of federally aided planning and research programs in the State highway or transportation departments.

According to unpublished statistics compiled by BPR, from 1960 through 1967 the research budgets of the State highway or transportation departments increased from less than $3 million to about $23 million and the BPR administrative contract program from less than $500,000 to about $7.1 million. In 1961 the American Association of State Highway Officials (AASHO) research program, known as the National Cooperative Highway Research Program (NCHRP), was created,[2] and in Fiscal Year 1964 the budget level for this program was about $3 million.

In 1964 the Illinois Highway Research Council studied how to be more effective in getting research findings into practice. Applying potentially useable research results was strongly emphasized and approaches were suggested for improving communications to make the research implementation process more effective. (*4*)

In 1966 the Illinois Division of Highways initiated discussions with AASHO to develop an organized and adequate plan to improve the implementation of research results from the NCHRP. This set off a chain of events leading to the establishment in June 1967 of an AASHO Special Committee on Utilization of Research Findings, which included representatives from State highway or transportation departments, the Highway Research Board, and BPR.

The Committee concluded that there was "without doubt an unnecessary and undesirable timelag between the conclusion of research work, resulting in findings that should be put into practice, and the actual widespread utilization of such information." (*5*) The Committee further stated that highway officials were aware of the problem but ineffective in correcting it for several reasons including:

"1. Researchers do not present their findings in the form or language that can be immediately translated into the media of practice.

2. Researchers do not fully understand the needs of practicing engineers and others whose problems are seldom communicated in terms of research need.

3. Practicing engineers are frequently suspicious of the findings from research and are hesitant to take the lead in trying something new.

4. Practicing engineers seldom have time to study the research work that led to conclusions that may be applicable.

5. The research program frequently does not provide funds for the comprehensive test and evaluation at the field level necessary to generate confidence in the results." (*5*)

The Committee concluded that the unnecessary timelag in implementing useable research results in practice indicated the lack of an organized approach to the research implementation process. Full-time professional generalists were recommended to provide the missing link between research and operations. (*5*)

In September 1968, BPR revitalized the Experimental Projects Program by issuing new instructions to simplify the administration of experimental features on construction projects to emphasize the implementation of research findings through this Program.

In 1969 the Demonstration Projects Program was established to promote and accelerate the adoption of new research results and innovative planning, engineering, and construction practices. New or improved technology is brought directly into a transportation agency and presented to the personnel most directly concerned with the particular technology. (*6*)

At the 48th Annual Meeting of the Highway Research Board in January 1969, Francis C. Turner, Director, Bureau of Public Roads, described the BPR's planned approach to research implementation. He defined implementation as, "The process of utilizing research findings through translation into operating methods and practice," and described the elements of a structured plan for the implementation process to enhance and accelerate the implementation of useable research results. (*7*) Elements of the plan included implementation committees or coordinators in the BPR regional offices and improved dialog between R&D and the operating offices in Washington, D.C. Principles that guide current Federal Highway Administration (FHWA) technology transfer efforts were defined including:

- Obtaining the full cooperation and interest of top management.
- Involving engineers at the operations level in the research and development process.
- Arranging for testing, and evaluating research products to insure implementability.
- Developing and implementing solutions to real world problems of practicing engineers.
- Preparing and presenting research findings in a format and language

[2] A. E. Johnson, Executive Secretary, AASHO, Letter to Mr. Fred Burggraf, Director, Highway Research Board, December 1961.

that are readily understandable and useable by field operations personnel.

- Providing specialized training and information programs to aid in adopting new technology.
- Providing a flexible and responsive management framework adaptable to immediate demands. (*7*)

1970–1980

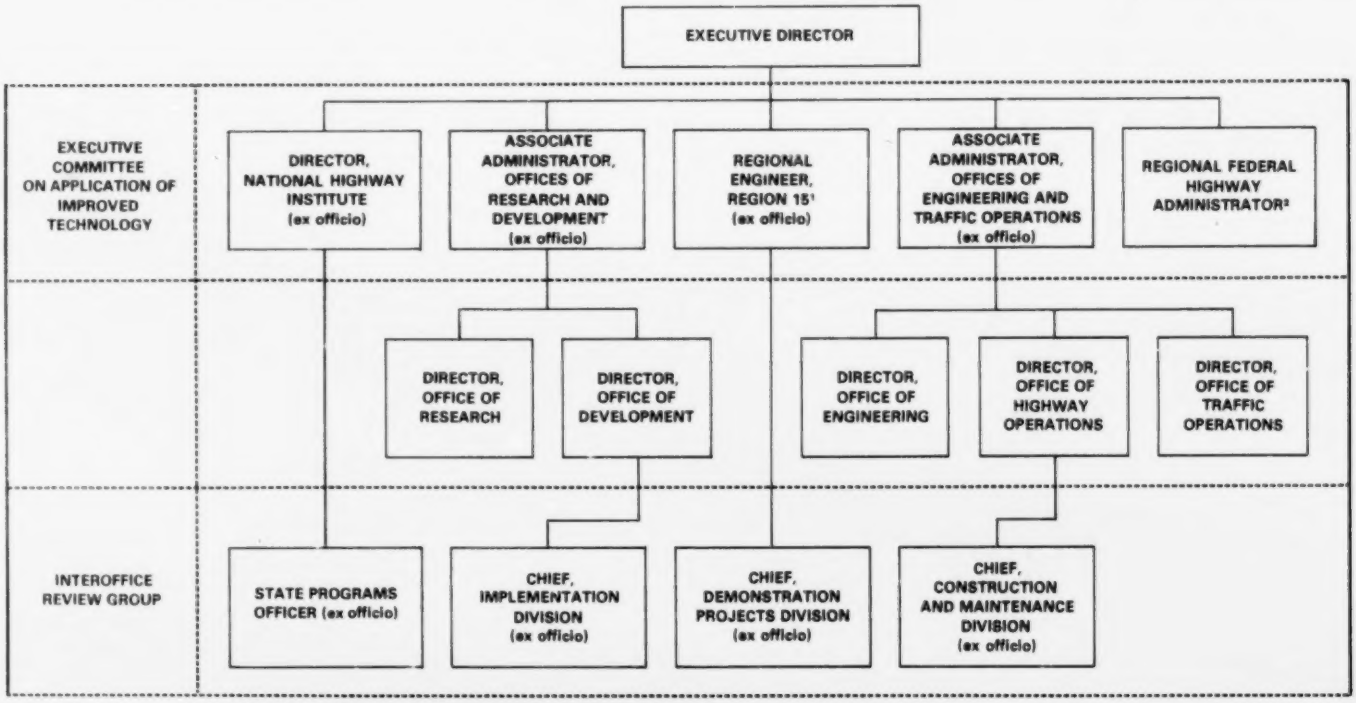
In 1970 the National Highway Institute (NHI) was created by the Federal-aid Highway Act of 1970 to develop and administer, in cooperation with the State highway or transportation departments, training programs for FHWA, State, and local highway agency employees. (*6*)

Also in 1970, the Implementation Division was established to develop, field test and evaluate, package, disseminate, and provide technical assistance on new technology. Information is received from FHWA's own research efforts, State highway agencies, and other programs within and outside of government. Material provided to users is in the form of a variety of publications, packages, kits, hardware, training programs, and data systems.

To avoid duplication of efforts and conflicts in program coordination, an FHWA Executive Committee on Application of Improved Technology (fig. 2) was created in November 1973 to provide central coordination control for implementing high priority technology transfer items. Responsibilities of the Executive Committee include establishing FHWA technology transfer goals, objectives, policies, and priorities. The Interoffice Review Group (IRG), a middle management working group composed of representatives from the Office of Development, Office of Highway Operations, National Highway Institute, and Eastern Direct Federal Division, also was established to screen and review individual technology transfer items, establish and modify specific implementation priorities, develop general and specific implementation plans, and make tentative budget assignments for high priority technology transfer items. (*1*) All technology transfer items originating from within and outside FHWA are reviewed by the IRG before work is authorized on the item.

Concurrent with the establishment of the IRG was establishment of regional and division technology transfer coordination positions in each of the FHWA field offices to provide the first coordinated

Figure 2.—FHWA Executive Committee on Application of Improved Technology and Interoffice Review Group.


EXECUTIVE DIRECTOR
EXECUTIVE COMMITTEE ON APPLICATION OF IMPROVED TECHNOLOGY
DIRECTOR, NATIONAL HIGHWAY INSTITUTE (ex officio)
ASSOCIATE ADMINISTRATOR, OFFICES OF RESEARCH AND DEVELOPMENT (ex officio)
REGIONAL ENGINEER, REGION 15[1] (ex officio)
ASSOCIATE ADMINISTRATOR, OFFICES OF ENGINEERING AND TRAFFIC OPERATIONS (ex officio)
REGIONAL FEDERAL HIGHWAY ADMINISTRATOR[2]
DIRECTOR, OFFICE OF RESEARCH
DIRECTOR, OFFICE OF DEVELOPMENT
DIRECTOR, OFFICE OF ENGINEERING
DIRECTOR, OFFICE OF HIGHWAY OPERATIONS
DIRECTOR, OFFICE OF TRAFFIC OPERATIONS
INTEROFFICE REVIEW GROUP
STATE PROGRAMS OFFICER (ex officio)
CHIEF, IMPLEMENTATION DIVISION (ex officio)
CHIEF, DEMONSTRATION PROJECTS DIVISION (ex officio)
CHIEF, CONSTRUCTION AND MAINTENANCE DIVISION (ex officio)

[1] Direct Federal Program Administrator has assumed this position.
[2] This representative selected by ex officio members on a rotating basis and serves 1 year.

national network for FHWA Technology Transfer Program efforts. These positions clarified the technology transfer delivery system, which is essential to the success of a Technology Transfer Program of the magnitude of FHWA's. In the 1980 FHWA regional reorganization, an Office of Research and Technology Transfer was established in each Region to recognize the importance of these functions within FHWA.

1980's and Beyond

Today, participation in the Technology Transfer Program is an important function of the FHWA Washington, D.C., Headquarters, Region, and Division Offices. Technology transfer is integrated into the everyday functioning of professionals within FHWA.

FHWA continues to structure the process, improve program outputs, and provide resources to accelerate the application of new or improved technology. The cost effectiveness of FHWA's Technology Transfer Program has been proven countless times as will be illustrated in this issue of *Public Roads* in the articles relating to the specific programs. FHWA top management, the Administrator and the Executive Director in Headquarters and our officials in our field offices, strongly support the Program. Without question, the highway community understands the benefits of a strong Technology Transfer Program in the future of highway transportation. Therefore, in 1990 when the accomplishments of the 1980's are assessed, technology transfer as it has been since the 1890's will be recognized as an FHWA priority function essential to the accomplishment of our national mission.

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(*1*) "Technology Transfer Program," FHWA Order 6000.1, *Federal Highway Administration,* Washington, D.C., Sept. 6, 1977.

(*2*) "America's Highways 1776–1976," *Federal Highway Administration, U.S. Department of Transportation,* Washington, D.C., 1976.

(*3*) "America's Highways, A History of the Federal-aid Program," *Federal Highway Administration, U.S. Department of Transportation,* Washington, D.C., 1977, p. 44.

(*4*) "Application of Research Findings to Engineering Practice," Committee Report, *Illinois Highway Research Council,* Oct. 27, 1964.

(*5*) "First Interim Report," *Special Committee on Utilization of Research Findings, American Association of State Highway Officials,* Washington, D.C., Apr. 1, 1968 (Rev. Apr. 15, 1968).

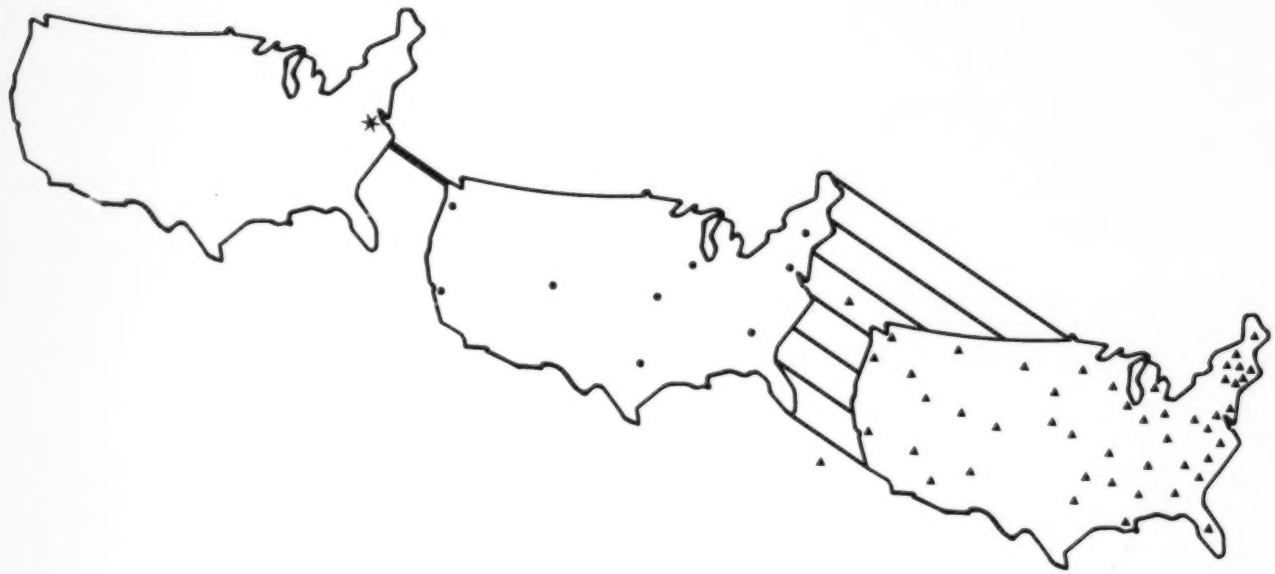
(*6*) "The Road to Technology Transfer," *Federal Highway Administration,* Washington, D.C., November 1979.

(*7*) F. C. Turner, "Implementation of Research Results: BPR's Approach," Presented at conference session on Utilization of Research Findings, 48th Annual Meeting, *Transportation Research Board,* Jan. 14, 1969.

Milton P. Criswell, formerly Director, FHWA Office of Development, retired in November 1981. As Office Director, he managed programs to develop practical applications for research results to be implemented including necessary field tests and evaluations, equipment development, and preparation of manuals, handbooks, training materials, visual aids, and computer programs for dissemination to the user. Mr. Criswell's career with the Bureau of Public Roads and the Federal Highway Administration spanned 28 years. Field assignments included area engineer positions in the New Hampshire, New Jersey, and Massachusetts Division Offices and research engineer in the Region 1 Office. Mr. Criswell transferred to the Washington, D.C., Headquarters Office in 1965 as a program officer for the Office of Research and Development. From 1972 to June 1980 he was Chief, Implementation Division.

Field Activities in Technology Transfer

by
Ray G. Griffith



Introduction

"The buck stops here." This phrase may be passe, but the words still apply to the user of technology. It is the user who must receive, evaluate, and decide to apply improved practices, procedures, materials, and techniques through a "media of practice" such as plans, specifications, standards, and operating procedures. Ultimately, the user of technology controls advancement.

In the highway community, the users of technology are found at all levels. However, the majority are located in the States, cities, and counties where highway transportation facilities are actually being purchased. It is at these levels where highway needs are identified and the necessity of applying new techniques, procedures, and practices to accomplish more with limited resources is most evident. Consequently, efforts to generate positive technological change are focused at these levels.

Technological change is needed to manage the incompatibility between increasing highway needs and decreasing resources. Research can point the way, but the results must be *transferred* into practice. Commitment to technology transfer is required by everyone involved in the highway program, including the Federal Highway Administration (FHWA) Region and Division Offices (commonly referred to as the "field offices").

The FHWA field offices are an important part of the technology transfer process because the staffs provide a link between many users at the State and local levels and outside sources of new technology.

This article reviews the roles of the field offices in the Technology Transfer Program. Selected activities, procedures, and approaches that are being used or have been used to fulfill these roles are discussed briefly. A few approaches to technology transfer used by State highway agencies also are described. Generally, the approaches selected are designed to facilitate the interface between FHWA and State users. Some of the approaches for delivering technology to the large "local" user group also are mentioned.

Roles of the FHWA Field Offices

FHWA's formal Technology Transfer Program was derived from the realization in the mid-1960's that technological advancement simply was outdistancing the application of new technology. The background of the Program, discussed in the previous article, and the FHWA organizational structure influenced the roles that have evolved for the field offices. The two main roles are:

1. To serve as a communications link among the various sources of new technology (including the FHWA Washington, D.C., Headquarters program offices, States, and industry) and those States and local highway agencies that can apply the technology in daily operations.

2. To encourage throughout FHWA and in State highway agencies organizational structures and personnel assignments that help transmit available technology from any source to actual field use.

Numerous functional statements and operational plans have evolved from the above roles. Almost as many approaches exist as there are FHWA field offices, and the functions of the Regions are distinguished from functions of the Division Offices.

Regional Office technology transfer functions

Although functional statements in an operational plan must be fairly detailed, the following general statements suggest some of the activities required to fulfill the roles.[1]

1. Identify and evaluate unique and beneficial research results and current practices for application at the State and local levels within the Region.

   a. Consider results and practices originating both within and outside Regional boundaries.

   b. Plan, develop, and use application aids such as user packages, demonstration and experimental projects, and training programs.

   c. Maintain communication with Headquarters elements of the technology transfer program, including recommending interregional application of Regional products.

   d. Perform surveillance and evaluation as appropriate to insure application of proven technology.

2. Develop and promote multidisciplinary programs for the application of promising research results in highway engineering within the Region.

   a. Develop viable organization structures and mechanisms in the FHWA Division Offices and State highway agencies for evaluation and application of new technology.

   b. Cooperate and interact with other elements of FHWA, State highway agencies, industry, and related organizations as appropriate to evaluate the effectiveness of the technology transfer programs.

Division Office technology transfer functions

Functional statements for the Division Offices are similar to those for the Regions, but usually reflect a direct interface with the State highway agency.[2]

1. Evaluate results from the State's research studies, identify implementation potential, promote use by the State, and communicate results of application to others.

2. Evaluate new technology items from sources other than State research studies and, if warranted, design and conduct promotional efforts with State, city, county, and other local users.

3. Encourage participation in the Demonstration and Experimental Project Programs.

4. Evaluate the results and benefits of the technology transfer process.

Field Approaches to Technology Transfer

Most FHWA field offices have a technology transfer coordinator. In some cases the Deputy Regional Administrator has been designated coordinator for the Region, and in other cases, the Director, Office of Research and Technology Transfer has this assignment. In the Division Offices, the Assistant Division Administrator usually is the technology transfer coordinator. Occasionally, the Field Operations Engineer, the Transportation Planner, the Bridge and Technology Transfer Engineer, or the Bridge and Research Engineer has been designated.

Several field offices now have active technology transfer committees that may function in different ways but generally are chaired by the designated technology transfer coordinator.

[1] These statements are generalized from operational plans for Regions 4 and 8.

[2] Statements extracted and generalized from FHWA North Carolina Division, "Plan of Operation for Division Technology Transfer Committee," adopted October 1976, updated April 1981.

The need for management support of technology transfer in the field was recognized in the program's infancy. The direct involvement of the Deputy Regional Administrator and the Assistant Division Administrators is believed to reflect such support and also facilitates the continuing involvement of all Regional and Division staff disciplines in ongoing operations. The implementation groups further facilitate this interaction and encourage cooperation among various disciplines.

The Florida and Utah Division Offices' approaches to technology transfer committee operations involve Division staff and include State highway agency participation as well. In Florida, the Director of Construction and Deputy State Materials and Research Engineer are members of the Division technology transfer committee. The State Engineer of Research and Development and the Implementation Engineer are members of the committee in Utah. Operation of both committees appears to be similar. Reports are screened by the committees to decide on the applicability of particular new technology. This is critical to any approach to the field technology transfer program. Both committees also have systems for tracking or monitoring technology items that are considered. (*1*)[3]

A new technology item remains on the Utah committee's agenda until it is decided whether or not to apply the item. Florida's approach is similar, with the Division technology transfer committee keeping current summaries on the many items that are delivered through the technology transfer program. This monitoring procedure enables followup—an activity that is also critical to whatever approach is selected for working the program. Most of the field offices have recognized this need. A 1978 national evaluation of the field technology transfer program by FHWA Headquarters revealed that "up to two-thirds of the Divisions have devised some type of inventory control by which they can assess the status of the various technology transfer efforts. This enables them to determine if they have been successful in having the State implement the item and keeps the various functional areas informed on items in their areas of responsibility." (*2*)

Some States also have developed monitoring systems. The Virginia Highway and Transportation Research Council uses a special "green sheet" to record specific research recommendations and to track these items until official action is taken. Florida's operating procedures provide the Director of Construction, who is also responsible for technology transfer in the Department, with a written evaluation on each item and a conclusion about its applicability. Utah uses a review form that is completed by the potential user group and returned to the Implementation Engineer. The implementation process in the Utah Department of Transportation is shown in figure 1.[4]

In addition to Division technology transfer committees where both State and FHWA personnel are members, there is the variation offered by Colorado where the Division Office coordinator is a member of the State's implementation committee.

In 1976, the Colorado Department of Highways established a technology transfer group in the Research Unit. In addition to supporting the implementation committee and its activities, the group has periodically presented exhibits and discussed research on Colorado highways and other technology transfer matters with personnel throughout the agency. The technology transfer program is reportedly better understood by Department staff as a result of the efforts. (*3*)

Other States also have established technology transfer units. Those involved in the 1978 national evaluation noted that "due largely to the efforts of our field people in the program, a dozen or so States now have technology transfer sections in their highway agencies, and the number is continuing to increase." (*2*) Indications are that States that have established technology transfer units have found them to be productive.

There may be other effective approaches to the technology transfer program. In South Carolina, for example, there is neither a formal State highway agency organization for conducting technology transfer activities nor a Division Office committee. However, a proportionate number of technology transfer items are being implemented. Apparently this is because the entire Division Office is involved in the program and a good professional relationship exists between State highway agency and FHWA engineers involved in a one- to-one type approach to technology transfer. (*4*)

The South Carolina approach, although not a formal one, reflects interest and enthusiasm for the program—important elements in any approach. "FHWA and State highway agency personnel serving in the technology transfer area must be enthusiastic about the 'positive change' potential of their work and, of necessity, be salespersons for the program." (*3*) This suggests that people make things happen and emphasizes the point that ". . . new ideas do not sell themselves—they often need help." (*5*)

[3] Italic numbers in parentheses identify references on page 144.

[4] "Manual of Instruction, Part 9, Research and Development," Draft document, *Utah Department of Transportation*, July 1976.

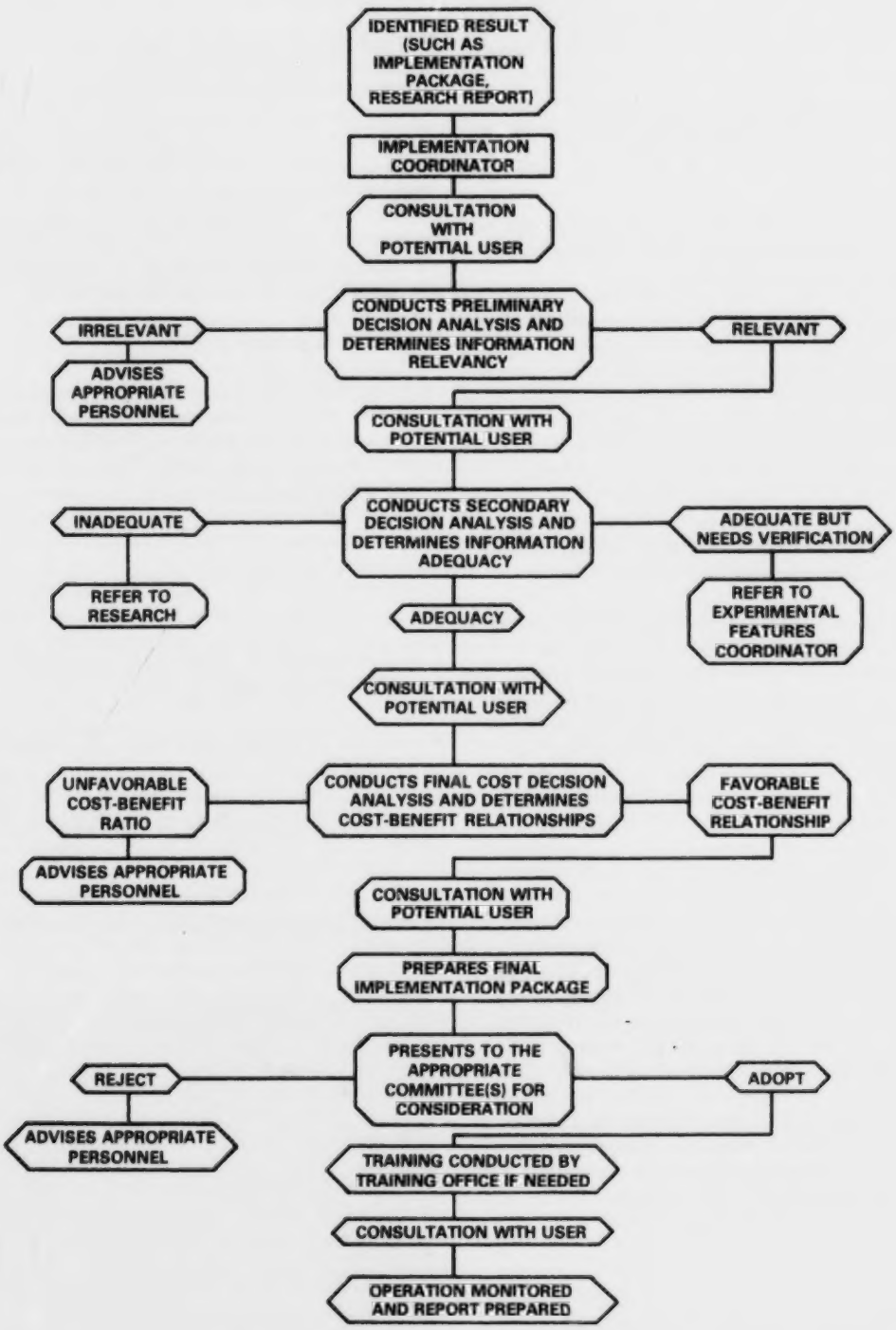


Figure 1.—Utah Department of Transportation implementation process.

Although other field office and State highway agency approaches to the technology transfer program could be described, it is suggested that the more effective approaches address the elements reflected in the preceding examples. The most critical of these elements follow.

- An assessment of the technology item and a conscious decision about its applicability to the operation of the particular unit for which it is being considered.
- The communication of the technology transfer item to the potential user in terms and in a method that facilitates assimilation and application.
- Enthusiasm for new and better ways of accomplishing the tasks at hand.
- A procedure for followup and feedback.

Further, these critical elements are most likely to receive adequate attention if the approach uses a structured technology transfer committee.

Field Activities Designed to Deliver Technology to Local Highway Agencies

Cities, counties, consultants, contractors, universities, and even other Federal agencies at the local level constitute a large group of potential users for much of the new highway technology. The group is significant because of its size and also is important when need is considered. "The Federal Government bringing its resources in technology right down to very practical things on the local level is a very good example of what we need."[5] This observation by a local official is appropriately interpreted as support for the transfer of new technology to the local level.

Similar indications are noted in North Dakota. In November and early December of 1979, the North Dakota Highway Department sponsored several "local public road workshops." These workshops generated information on road issues and problems confronting local units of government that led the workshop coordinators to recommend the following:

- The initiation of a quarterly construction and materials newsletter to keep local road departments aware of changes in technology related to construction and maintenance of highways.
- Actions to improve the availability and kind of training offered to local road department employees. (*6*)

Many field offices and State highway agencies have taken on the challenge of delivering technology to cities, counties, and other groups. Brochures with franked forms for convenient ordering of technology documents have been distributed; some States and Divisions have established mailing lists and distribute these brochures regularly. In addition, field offices and States have participated in meetings of local groups, published newsletters, provided workshops and seminars, and participated in exhibits. The following are examples of successful activities.

Region 9 Roadshow

Among field office technology transfer activities directed toward local governments, perhaps the most aggressive is operated by FHWA's Region 9 Office of Research and Technology Transfer in San Francisco, Calif. The effort, called the Roadshow, approaches delivery through technology transfer presentations to local agencies, city and county associations, and a number of special district groups. The Roadshow is complemented by a quarterly newsletter, "Technology Transfer Update," which describes recent activities as well as new items in the technology transfer program to a large number of recipients. Response to the newsletter has been excellent.

A catalog of technology transfer presentations is provided to representatives of local groups for use in selecting items to meet their specific needs, although presentations are tailored on request. A unique feature of the effort is the housing of projection equipment and the Region's film library in a van dedicated to the Roadshow. The van is used in responding to invitations to participate in meetings, and the availability of the film and audiovisual equipment enables spontaneous response to group needs. In Fiscal Year 1980 the Roadshow effort resulted in 50 presentations to 1,600 people. Division Offices and State highway agencies in Region 9 fully support the Roadshow.

Workshops and seminars

At a conference on research and development management for transportation research and development managers it was concluded that officials and staff of local governments are best informed about new highway technology through such mediums as construction conferences and association meetings. (*7*) Among the State highway agencies using these mechanisms is the Georgia Department of Transportation, which has established technology transfer as a major function of the Operation Branch in the Research and Development Bureau. The training-through-workshops approach has been used to spread

[5] Mayor C. Reynolds, West Hartford, Conn., in the video tape "Intergovernmental Management: The Task Ahead," by the Study Committee on Policy Management Assistance for the U.S. Office of Management and Budget, Washington, D.C., *National Audiovisual Center*, 1975.

new technology throughout the State. A workshop on road maintenance training programs, for example, was held for cities and counties in seven locations. (*8*)

The Utah Department of Transportation recently built the modified excess oxygen burner device for pavement stripe removal and demonstrated it throughout the State for local officials as well as for its own personnel. The Virginia Highway and Transportation Research Council has held three technology transfer workshops for cities and towns and expects to continue this activity annually.

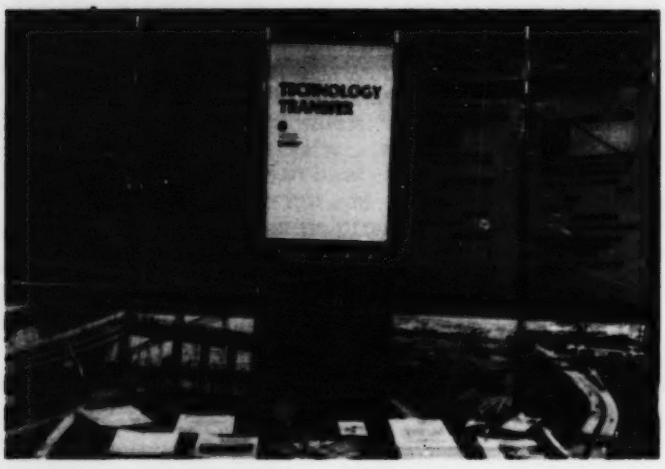
Participation in exhibits

Several field offices have initiated technology transfer booths at State highway conferences, various secondary road and public works meetings, engineering society meetings, selected technical conferences, and in connection with college- and university-related activities. (*2*) The attractive standup display shown in figure 2 portrays each of the four Headquarters technology transfer elements. Handouts are arranged on a table in front of the display.

University Public Service and Research Association

Other groups outside of official highway agencies are interested in technology transfer. In several colleges and universities, small groups respond by telephone and with onsite consultation to problems brought to their attention by local officials. Those involved in this activity have organized the informal University Public Service and Research Association. Partial funding by the National Science Foundation helped initiate this program.

Figure 2.—Standup technology transfer display used in exhibits.



Conclusion

The University Public Service and Research Association demonstrates the fact there are groups outside the official highway community interested in the transfer of technology to local agencies. Other groups could be cited. These groups may offer viable channels that can supplement field office and State highway agency efforts to deliver new technology directly to cities and counties. The challenge is to be sensitive and respond positively to opportunities to work with these groups, assisting in both delivery of technology and maintaining an internal awareness of new technology.

Other approaches to working with local units of government probably exist, just as there are activities and procedures for field office and State highway agency technology transfer interactions that have not been included in this article. The examples that have been mentioned were selected because an active approach—a desire for positive technological change—was reflected even though a formal technology transfer structure might not be operational. It seems clear that new technology is being applied more rapidly where the approach to technology transfer is active rather than passive.

New technology has been applied over the years and will continue to be applied even with a passive approach. The rate at which technology is applied generated the concern evident during the late 1960's and early 1970's. This is a viable concern today when the economic environment demands accomplishing more with less. New practices, procedures, materials, and techniques that help meet highway needs must be sought and applied.

The entire highway community has a role in responding to this demand. The role of FHWA field offices is to identify and communicate efficiently new technology to potential users at the State and local levels. Encompassed in this role is a sensitivity to the existence of new technology within a State or Region, determination of the technology's potential benefit to the highway program, and the development and communication of the product to users. The role includes field office interaction with the FHWA Headquarters technology transfer elements, reporting new technology developed locally, receiving products from external sources, using available communication tools, and providing information on productive technology transfer items. The role also involves

interaction with numerous other sources and users such as universities, consultants, contractors, and suppliers. In short, fulfilling the role expands the State and local users' sources of new technology and enhances the understanding, evaluation, and application of the technology.

Technological advancement is recognized as a kind of spiral with no identifiable beginning or end. The technology transfer process discussed in this article, however, begins with the research product and concludes with its deployment in the highway program. FHWA field offices, as members of a much larger team, are an important part of that process. Yet, in the end, it is the entire highway community's commitment to providing a safe and efficient highway transportation system in the most cost-effective manner that makes advancement a reality.

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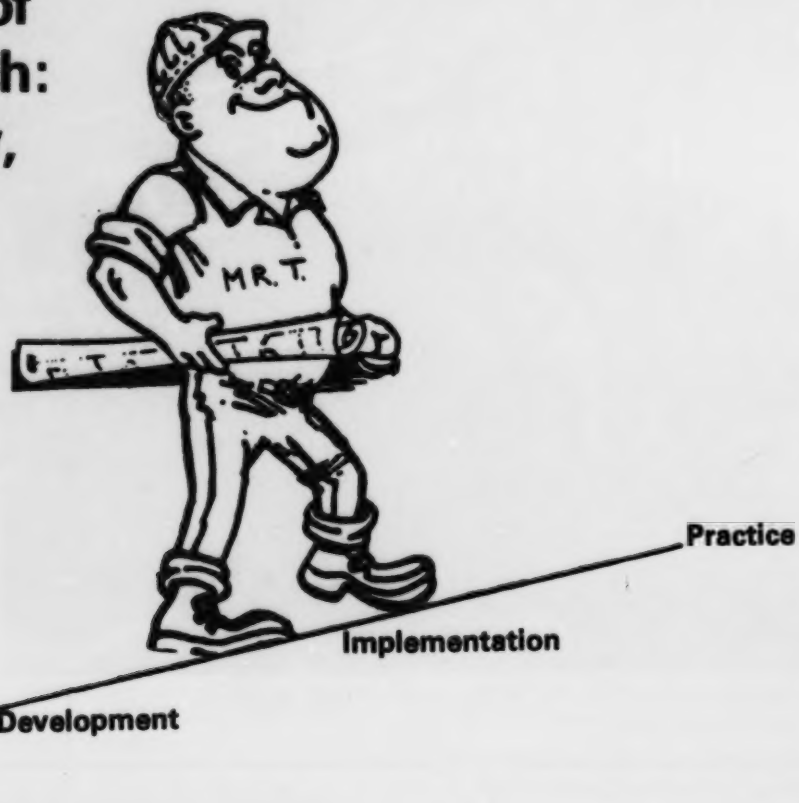
Ray G. Griffith is Director, Office of Research and Technology Transfer in FHWA's Region 8 Office, Denver, Colo. He has a strong interest in technology transfer, becoming actively involved in its programs in 1969 as Regional Research Engineer in Kansas City, Mo. Before that he served as Assistant Planning and Research Engineer and as an assistant area engineer in the Missouri Division. Before joining FHWA in 1966, Mr. Griffith worked in Topeka for the Kansas Highway Commission as Field Soils Engineer and as a project engineer in Hays, Kans.

Additional information on the field office technology transfer program can be obtained by contacting the FHWA Regional Offices (see page 178).

Implementation of Highway Research: Yesterday, Today, and Tomorrow



by
Robert J. Betsold

Introduction

A new golf ball has been produced. You are encouraged to try it because it flies farther and straighter than other balls, and stops better on the green. A toothpaste sample received at the supermarket promises brighter teeth, fresher breath, and fewer cavities. Advertising campaigns on radio and television, in newspapers and magazines, on billboards and buses all praise new products. Is all of this cost and effort really necessary? Yes, because new products and ideas do not sell themselves—they must be brought to the attention of the consumer.

The marketing effort in private industry has a counterpart in the public sector. This effort, technology transfer, has been used by many agencies to encourage further application of the results of Government-sponsored research and development (R&D). An indirect but substantial benefit of the U.S. space program has been the new materials and technology produced and transferred by the National Aeronautics and Space Administration. Much of this technology has benefited the everyday lives of the American people. Technology transfer and technical assistance by the U.S. Department of Agriculture to the Nation's farmers also have provided substantial benefits. In this program, county agents successfully have linked agricultural science to farm practices.

Yesterday

In the highway program, technology development has a long history. Research was one of the principal missions of the first national highway program in the United States and is, in fact, the oldest continuous Federal highway activity.

Over the years, various methods were used to transfer research findings and make highway expertise available to the Nation. These included the Object Lesson Roads Program (1897–1910), the Good Roads Trains (1901–1903), and the Road Improvement Trains (1910–1916). (*1*)[1] Also *Public Roads* magazine, first published in 1918, has served to widely disseminate research findings to the highway community.

In 1920, the National Advisory Board on Highway Research (later known as the Highway Research

[1] Italic numbers in parentheses identify references on page 152.

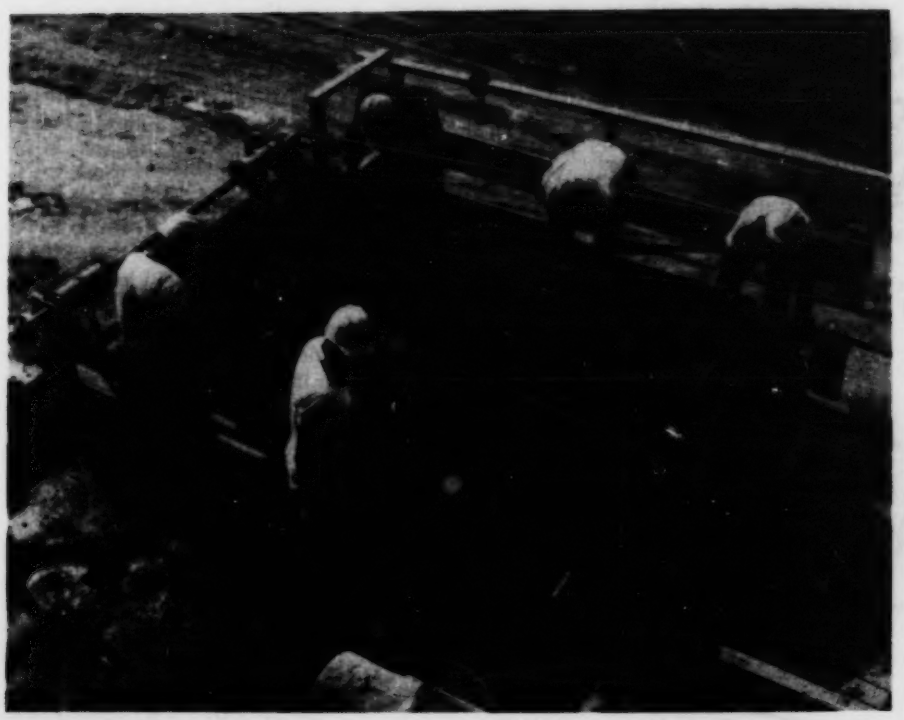


Figure 1.—Production cost study on mixing times for large central mix concrete plants—North Haven, Conn., 1964.

Board and now the Transportation Research Board) was established to "collect and distribute information." Mr. Roy W. Crum, Director of the Highway Research Board from 1928 to 1950, stated, "The end product of our work is useable technical information, but it will be of no value to anyone unless it is learned and put to use by the technical man." (*2*)

Federal-aid for State highway planning and research began with the Hayden-Cartwright Act of 1934. With the approval of Federal funds for State highway research and testing activities, communication between Federal and State researchers increased. Transfer of highway technology also advanced through many Federal-State cooperative activities including various road tests to study pavement performance, production cost studies to analyze the use and operational efficiency of construction equipment (fig. 1), accident evaluations of the Interstate Highway System, and highway capacity studies.

Through the years, there was a strong movement to expand and strengthen the practical use of highway research. However, in the late 1960's it became apparent that highway transportation problems were becoming too large and complex, and insufficient attention was being given to putting the extensive research findings into practice. Skilled promotion was needed to gain managerial support, to overcome inertia and resistance to change, and to insure the essential actions for public acceptance. (*3*)

Responding to this problem, the Federal Highway Administration (FHWA) created a separate Office of Development in 1970. After initial adjustments, the R&D organization was structured as shown in figure 2.

Within the new Office of Development, the Implementation Division specifically was assigned to provide "leadership in the entire implementation process" and to serve as the "control, coordination, and management activity for translating into practice the results of research and development." (*4*)

Today

With the cooperation of the Office of Research, FHWA program offices, and the Interoffice Review Group (described on page 136 of this issue), the Implementation Division has, for the past 10 years, provided the desired linkage between research and practice. This effort has been successful because of good staffing practices, strong financial and program support, a logical hierarchy of implementation techniques, good cooperation with program offices in the Washington, D.C., Headquarters, and a well organized and geographically distributed field structure to encourage hands-on application of new technology.

Staffing practices

During the 1970's FHWA strongly encouraged geographic mobility among its employees. The Implementation Division supported this policy and benefited from the flow of engineers from the field offices. These engineers were promoted to implementation manager positions in Headquarters with the understanding that they could return to the field after a 2- to 5-year assignment. Working with senior managers in the Implementation Division, these implementation managers became knowledgeable in areas such as highway safety, traffic engineering, environment, and pavement management. With their general engineering background and field experience and their on-the-job training in implementation techniques, they provided the

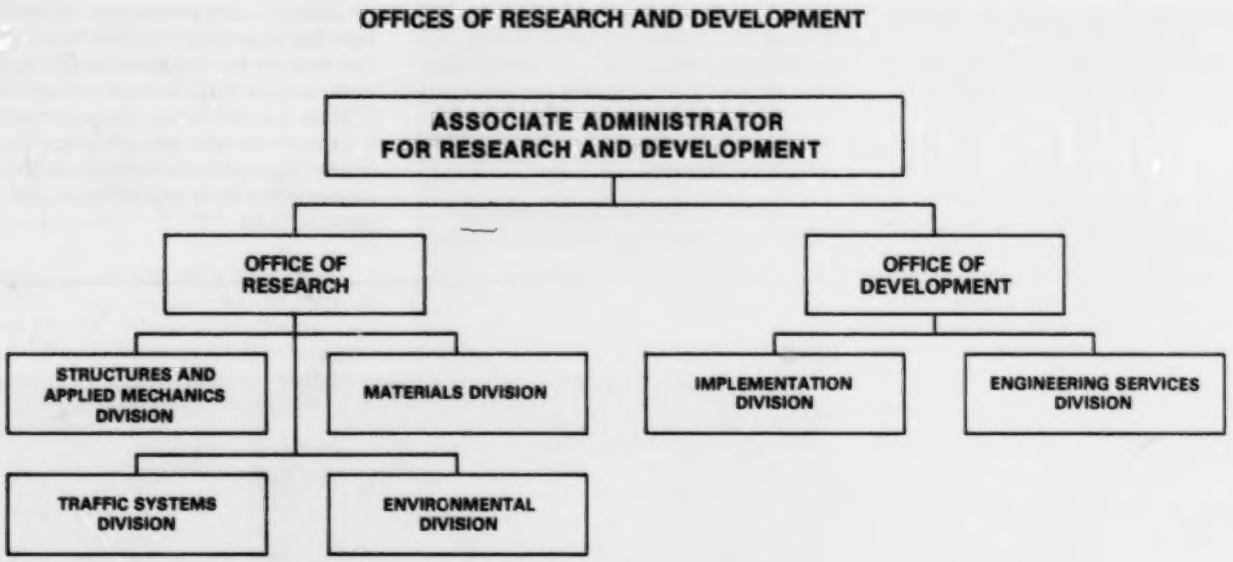


Figure 2.—Offices of Research and Development organization.

missing link in the research-to-practice chain. Most of these engineers were highly successful in translating the technical jargon of the researcher into useable information that could be readily understood and accepted by field engineers. As an extra benefit, when they completed their assignment and transferred back to the field, most retained their interest and involvement in technology transfer activities.

Program support

The implementation program was well supported by agency policy and financial resources. Technology transfer was identified in 1975 as a specific FHWA Program Emphasis Area. In addition, approximately 15 to 20 percent of the annual R&D administrative contract funds were allocated to implementation activities. Compared with other Government agencies, this represents a substantial commitment of the R&D resources. The Stevenson-Wydler Technology Innovation Act of 1980 requires certain Federal laboratories, after September 30, 1981, to allocate at least 0.5 percent of the agency's R&D budget "to support the technology transfer function at the agency and at its laboratories." (*5*) Obviously, the FHWA program far exceeds the Congressional requirement.

Implementation techniques

A variety of methods are used to test and evaluate research findings and to pass the technology to potential users. Methods involving active participation of the user are selected for items with the greatest need or implementation potential. Methods used include:

- Training course development and pilot presentations.
- Conferences, workshops, and seminars.
- Industry disclosure meetings.
- Task orders with State highway agencies.
- Technical assistance by R&D staff.

Other high priority items considered to be of national interest are disseminated through active promotional materials including: films, video tapes, slide-tape presentations, and computer programs.

The least expensive means of dissemination involves written materials including: implementation packages, programed instruction training materials, user manuals, handbooks and guides, technology sharing reports, technical advisories, and brochures.

These materials are prepared by private industry, universities, nonprofit organizations, FHWA R&D staff and program offices, other Federal agencies, and State, county, and city highway agencies. The cost and quality of the items vary, but the intent remains the same—to get the material to the potential user in a readily understood and accepted form.[2]

[2] A detailed explanation of the FHWA implementation process is found in "Getting Research Into Practice," by Gerald D. Love, *Public Roads*, vol. 42, No. 2, September 1978, pp. 41–47.

Cooperation with program offices

The implementation program is solidly supported within FHWA. Program office managers recommend activities for the annual program, and their staffs help the Implementation Division staff prepare requests for proposals. Program office personnel also provide valuable technical advice by serving on proposal evaluation panels and monitoring the activities through the final product distribution stage. At that time, program offices frequently become the principal sales force for the new technology.

The implementation program has been designed to accept targets of opportunity or high priority items that occur. This flexibility is essential because R&D is a service organization, and timely response must be available to meet the needs of Headquarters and field offices.

FHWA field structure

The FHWA field organization (described on pages 138–144 of this issue) is a major factor in the success of the implementation program. Research and technology transfer directors in each of the nine FHWA Region Offices distribute and promote materials received from Headquarters. Staff in the FHWA Division Offices located in each State insure that materials reach appropriate staff in the State highway agencies. Like the county agents in the U.S. Department of Agriculture, FHWA Divisions provide the final, face-to-face link to encourage the acceptance of new ideas or materials.

Success Stories

A few of the many implementation successes of the R&D program include:

• *Dryer Drum Mixer.*—Development and evaluation of the dryer drum mixer for producing hot-mix asphalt concrete led to the widespread adoption of this innovation in asphalt paving.technology (fig. 3). Virtually all new hot-mix plants currently sold in the United States use dryer drum mixers because the capital and operating costs are significantly lower than the costs for pug-mill mixers.

• *Traffic Controller Synchronizer (TCS).*—A low-cost technique for wireless interconnection of traffic signals at urban intersections was developed to improve traffic flow and reduce fuel consumption. The TCS is a solid-state, time-based unit that coordinates existing traffic signal controllers without expensive interconnecting cable, radio, or optical links. (*6*)

Figure 3.—Adoption of dryer drum mixer technology.

• *Soil Stabilization in Pavement Structures.*—This users manual was cited by a national industry organization as a fine example of putting Federal money to excellent use and selected by the National Lime Association and the National Ash Association for distribution to their members.

• *Raised Pavement Markers in Construction Zones.*—At the request of the FHWA Office of Highway Safety, the Offices of R&D initiated a study with eight States to evaluate the use of raised pavement markers for construction zone delineation. The study concluded that raised pavement markers provide excellent temporary delineation and nighttime accidents are reduced, thereby justifying the cost of the markers. At least 13 States have now adopted this practice.

• *Value Engineering Studies of Selected Maintenance Activities.*—Since 1974, the Implementation Division has initiated 12 separate studies using value engineering techniques to analyze maintenance activities. Each study, conducted by teams of engineers from three or four States, determined optimum maintenance methods for specific activities such as shoulder maintenance, bituminous patching, mowing operations, and bridge painting. Annual cost savings for the States involved in the studies have been estimated to be over $8 million.

• *Self-Powered Vehicle Detector (SPVD).*—This wireless detector (fig. 4) was developed over an 8-year period by the Office of Research. After field tests and evaluations demonstrated the effectiveness of the SPVD, an industry disclosure conference was held in 1981. Representatives of the traffic control and electronics industries are considering commercial production of this device, and strong interest has been shown by State and city traffic engineers.

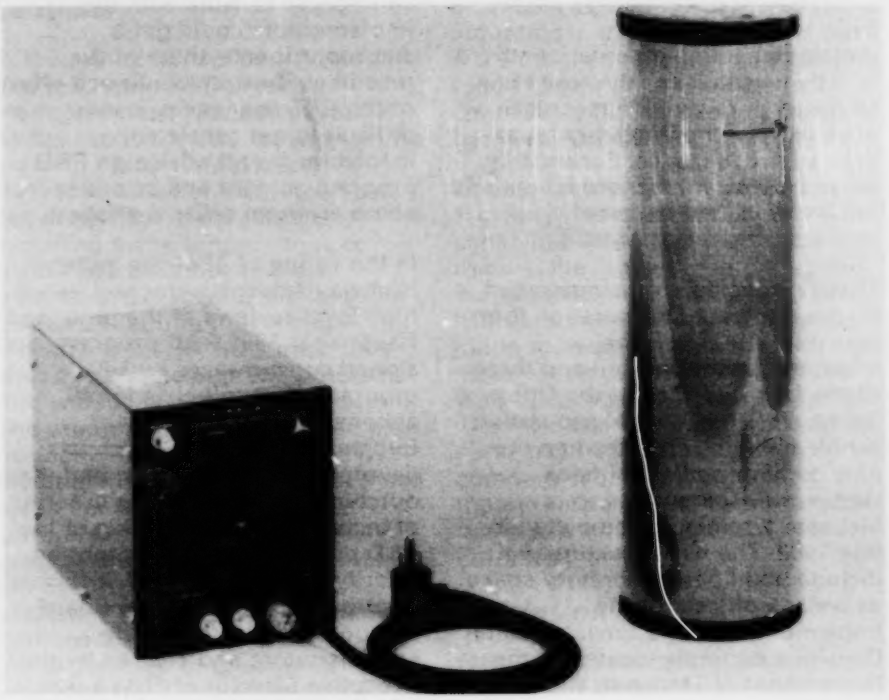


Figure 4.—Self-powered vehicle detector.

Other examples of successful applications of research results include the Urban Traffic Control System (UTCS), hydraulic design of bridges using risk analysis, use of polymer concrete materials, pavement stripe removal by high temperature burning with excess oxygen, and snowplowable pavement markers.

Tomorrow

Although the implementation program was successful in the 1970's, additional improvements and refinements are needed to meet the problems of the 1980's. Both the technology transfer program and the Offices of R&D organizational structure recently have been reviewed by the FHWA Office of Management Systems. These reviews, and independent assessments by R&D managers, have revealed important issues and suggested positive actions to improve the implementation process. The major issues, and actions being considered to address these issues, are as follows:

1. There is a need for greater collaboration between the researchers and the implementors to eliminate the hand-off that can occur from research to development. The researcher initiates the original work and pursues the study to conclusion of the research phase. The research results are then handed to the implementor for any necessary field test and evaluation, refinement, packaging, and promotion. Although this system can work, there are disadvantages. First, the implementation potential of a research study may not be considered during the earliest stages of the research process and such consideration is essential because the FHWA R&D program is an applied program, and work should be undertaken to fill an existing or anticipated need.

Second, when technology passes from research to development/implementation, there is little incentive for the researcher to continue to provide technical advice or for the implementor to seek such assistance. Fortunately, there are many instances where this professional and personal interaction is maintained.

These problems are compounded by the geographic separation that now exists between the Implementation Division and three of the four Divisions in the Office of Research. This physical separation problem will be solved when the new addition to the Fairbank Highway Research Station in McLean, Virginia, is completed in late 1982. The new structure will include additional laboratory space as well as offices for the Implementation and Environmental Divisions currently located in the Department of Transportation Headquarters in Washington, D.C. Co-location should encourage greater contact between the researchers and the implementors.

To smooth the transition from the research phase to the development phase the project team approach to technology development and transfer should be emphasized, with the researcher having a lead role during the early stages of the process and the implementor assuming greater responsibility in the later stages. Special talents of the researchers and the implementors can be combined throughout the process to create a synergistic effect, resulting in research activities responsive to genuine needs and final products technically sound as well as useable by the practitioner.

2. Until recently, there have been no formal mechanisms for determining with the program offices which research outputs should receive priority for implementation. Interaction occurred at the staff working level, and those people in the program offices who displayed the greatest enthusiasm and willingness to work with the implementors could get a disproportionate share of the resources. Despite continued efforts of top R&D managers, it was difficult to get consistent involvement and advice on R&D program content and priorities from some program office managers.

In the spring of 1981 the Federal Highway Administrator requested high level reviews of the proposed Fiscal Year 1982 R&D program, and signed concurrences by key program office officials for all actions exceeding $50,000. Substantial time and effort was devoted to these reviews, and the outcomes were gratifying in terms of increased understanding of the R&D program and agreement on priority actions. Recently, a formal Contract Program Review Board composed of key associate administrators and chaired by the Executive Director of FHWA was created for "assessing individual requirements in the light of overall FHWA program priorities, and for insuring the appropriateness and cost effectiveness of the methods used to satisfy program needs." (7) This high level interest and involvement will assure that the R&D program is truly responsive to the overall needs of the agency.

3. The financial crisis that affected State and local governments in the 1970's has now reached the Federal level. Personnel and budget cuts are already occurring, and actions to reduce costs and increase efficiency will continue to be emphasized in the coming years. Reviews of the Offices of R&D organization have indicated several actions that could consolidate activities and reduce the management structure. Depending on the depth of the cuts, it may be necessary to eliminate some of the current services or programs provided by R&D. Regardless of the final form of the organization, the implementation function will be continued. During recent reviews of one of the proposed organizational changes, program offices in Headquarters and FHWA field offices voiced overwhelming support for the implementation activity.

4. The implementation program should continue to be evaluated to insure that necessary activities are undertaken and that high quality materials are reaching the intended audience. Feedback from FHWA field offices and from State and local highway agencies is essential for program evaluation. Feedback systems have been discussed with FHWA Regional Directors of Research and Technology Transfer, and a reporting form is being reviewed. The information should help to keep the program on track and provide data needed for Congressional budget reviews.

5. New or improved methods for technology transfer to city and county highway agencies and to special target groups must be explored. The problem of reaching local governments with new technology is augmented by the number of agencies involved. In New York there are over 1,600 local government units with highway or bridge responsibilities and over 2,600 such units in Pennsylvania. Various means have been used to inform these local agencies about new highway technology. In some instances the State highway agencies have local road units that technically assist or inform the local units. In other cases State universities have outreach programs that provide technical guidance or conduct periodic short courses for county and city engineers. In the implementation program, brochures announce the availability of new technology and include an order form so the report

or manual can be purchased from the Government Printing Office. These brochures are distributed to mailing lists maintained by the FHWA Division Offices or by the State highway agencies. New technology items applicable to local governments also are announced through newsletters or magazines published by such organizations as the Institute of Transportation Engineers, the Urban Consortium, the National Association of Counties, and the National Association of County Engineers. In addition, some new technology items are cited by trade journals or magazines such as *Paving Forum, American City and County, Public Works, Rural and Urban Roads,* and *Better Roads.* With cutbacks in Federal printing budgets and new restrictions on Government publications, these organizations and publications will be relied on more heavily to spread the word.

Even within State highway agencies it can be difficult to reach potential users. A recent study of highway maintenance research needs recommended that the "highest priority be directed to expediting and initiating a new, more effective program for R&D implementation and technology transfer for highway maintenance." (*8*) A study to address this problem is included in the Implementation Division's Fiscal Year 1982 contract program.

This delivery problem also is reflected in other areas. Reviews of suggested research problem statements for the National Cooperative Highway Research Program and responses to FHWA research problem solicitations consistently reveal problem areas where R&D has already provided solutions. Unfortunately, the technology is not reaching operational personnel in many States and is reaching even fewer counties and cities. Continued efforts in this area will be needed.

Cautions

In the zeal to consolidate operations and refine the R&D process, managers must proceed cautiously so the capability and strength of the existing system are not lost. An increased focus on outputs should not deter R&D managers from including some longer range or higher risk activities in their programs. Because of the long leadtimes required for major research projects, R&D must look ahead and anticipate the problems that will face the highway program. The program must also include high risk activities when warranted by the potential payoff. In each of these areas the R&D managers must continue to defend some of their programs against an operational philosophy that naturally focuses on yesterday's and today's problems. Perhaps these managers could cite the experience of Chester Carlson who took his Xerox invention to over 20 companies before he was able to make a sale. No one except Carlson himself envisioned the need for his process or believed that it was practical. (*9*)

Care also must be exercised if the project team approach is expanded. The highly technical orientation of the researchers must be retained and they must continue to have the opportunity and facilities to conduct original research. The current R&D staff includes nationally and internationally recognized experts in many areas of highway technology. This outstanding technical expertise has been a major and continuing factor in the value and success of FHWA and its predecessor organizations. At the same time, the value of the experienced generalist, who can develop, field test, evaluate, and translate new technology to user language, must be acknowledged. The generic problems of technology transfer identified in the 1960's can reappear if the trained implementation staff is lost. These individuals must continue to fill the missing link between research and practice.

Finally, the move to the Fairbank Highway Research Station will consolidate the R&D staff but remove the implementors from their current proximity to the program offices. Concerted efforts must be made to insure that frequent, personal contacts are maintained with the program office personnel. The R&D staff cannot effectively serve from afar; good communication, understanding, and mutual respect must be nurtured by managers on both sides of the Potomac.

Conclusion

FHWA has a successful history of technology development and transfer. As resources and requirements changed over the years, the policies, programs, and structures were changed to meet new challenges. The challenges of the 1980's are here, and changes and improvements must be made to meet the needs for greater efficiency and effectiveness in government. As part of this effort, closer ties between the researchers and implementors are essential, and they must team with the program offices to deliver new solutions to the Nation's highway problems. As DuPont Vice President Robert Hersey has observed, "Research per se is not a suitable objective. Research and its application, taken together and viewed as inseparable, are the legitimate goal." (*10*) This must be the goal for the FHWA R&D program in the 1980's.

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Additional information on the Implementation Division and technology transfer can be obtained by contacting the FHWA Regional Offices (see page 178) or

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Demonstration Projects Program

by
Douglas A. Bernard

Introduction

To receive maximum benefits from the results of large-scale research and development efforts, the results must be implemented quickly and widely. Often the most promising highway research results never become operational, not because of any inherent inadequacy of the research but because the field engineers do not have the time and resources to analyze useful research and translate it into operation. Also, to accelerate the implementation of research results, those engaged in research must communicate well with those engaged in administering operational programs. One effective means of improving this communication is to show, by an actual demonstration, how the results of research can be applied to an actual operational situation.

The demonstration project activity has a long history in the Federal Highway Administration (FHWA). The construction of projects under the Object Lesson Roads Program around the turn of the 20th century forcefully demonstrated the "seeing is believing" philosophy.

The science of highway engineering gradually developed as a function of laboratory research and through a continued program of incorporating experimental features into highway construction and then observing performance under traffic. Historic examples include test road projects in Illinois and California, the Bureau of Public Roads test track in Arlington, Virginia, during the early 1920's, and post-World War II test roads in Maryland, Idaho, and Illinois. (*1*)[1]

In an effort to continue to analyze and translate research results and improve communication by demonstrating the results, FHWA established the Demonstration Projects Program in 1969. The prime objective of the Program was to promote and accelerate the widespread adoption and use of practical highway research results and their application to innovative planning, engineering, and construction practices. (*2, 3*)

[1] Italic numbers in parentheses identify references on page 159.

Program Location

The Demonstration Projects Program is organizationally located in the Eastern Direct Federal Division (EDFD), Region 15, the designated principal field office responsible for administration of the Program. (*4*) To properly analyze and appreciate this relationship, the overall mission of FHWA, which includes the administration of a Direct Federal Projects Program, must be considered. Part of FHWA's activities in fulfilling its mission include providing transportation agencies throughout the United States with knowledge of the state of the art in the planning, design, construction, operation, and maintenance of highways and appurtenant facilities. FHWA has been recognized as an organization which has one of the best, if not the best, technology transfer efforts within the Federal Government.[2] This technology transfer requires engineers trained in the many highway engineering disciplines who must recognize research and development products or innovative practices that may improve current practices. The Demonstration Projects/Direct Federal Program relationship does much to provide and maintain this required high level of expertise.

Demonstration Projects/Direct Federal Program relationship

EDFD, Region 15, provides an excellent training ground for engineers, not only for those in the formalized FHWA training program but for others at various career stages. The inservice training program can be expanded to give specialized design and construction experience to selected engineers as part of a career development program. They learn the physical and personnel problems dealt with by State transportation agencies, as well as gain technical expertise in particular areas of interest. Their firsthand experience is invaluable in their future administration of the Federal-aid Program.

Direct Federal keeps abreast of, or ahead of, the state of the art in highway engineering. Several items included in the Demonstration Projects Program were conceptualized and developed by engineers in Direct Federal. Also, new research technology can be applied in an everyday "production" environment. EDFD, Region 15, like State highway agencies, provides a good testing ground for the practicality of new technology to be demonstrated and an opportunity to "debug," as necessary, before demonstrating it to other agencies.

The successful demonstration of new technology to other agencies must show that the technology can be applied by the level of personnel employed by the agency. The ability of EDFD, Region 15, engineers and technicians to relate to the highway department personnel through "peer communication" has been invaluable in promoting new technology.

EDFD, Region 15, provides an excellent source of staff engineers who collaterally act as demonstration project managers while performing their everyday work assignments. The special areas of expertise, such as geotechnical, materials, hydraulics, photogrammetry, and computer sciences, if not available through the Direct Federal staff, would severely hamper technology transfer efforts in these areas. This dual use of the staff engineers has proven to be an efficient and effective use of personnel.

A successful Demonstration Projects Program requires a high degree of organizational support and flexibility to accomplish the myriad of tasks involved to design, mobilize, and demonstrate new technology. The Demonstration Projects Program has ready access to EDFD, Region 15, in-house support functions including personnel and financial management, administrative services, procurement, and automatic data processing.

Program Operations

The Demonstration Projects Program is administered and operates as a service to the States and their political subdivisions as personnel and funds permit with minimum interference to the administration of the Federal-aid Program and with as few strings attached as possible. New technology included in the Program is promoted on its own merit and no pressure is applied to any agency to adopt or even try the item. This low-key approach generally has been successful.

Technology transfer coordinators in FHWA Region and Division Offices are responsible for letting highway agencies know what is available in the Demonstration Projects Program. When the actual demonstration is ready, an announcement is prepared and issued to highway agencies by the Office of Highway Operations. A project flier also is distributed to advertise and promote the project. In addition, a Demonstration Projects Program notebook is available to all Region, Division, and State Offices. This book periodically is updated with information on the Program's active projects and Program personnel.

Any agency desiring information or a demonstration presentation is advised to contact the FHWA Division Office in their State. That request is then forwarded through appropriate channels to the Demonstration Projects Division with a recommended course of action. Division Offices are urged to assess current agency practices relative to the technology being promoted in

[2] Lee L. Verstandig, Assistant Secretary for Government Affairs, DOT memorandum to Operating Administrator, June 3, 1981.

the project. Only those agencies that have not adopted the new technology for general use would be recommended for a project presentation and technical and financial assistance to construct and evaluate a pilot demonstration installation.

Attempts always are made to honor the requested times for project presentation, however, travel costs and prior scheduled presentations can affect scheduling. In some instances, demonstrations that require the use of traveling vans or tractor-trailer rigs are scheduled on a regional or sectional basis to reduce travel costs.

Organization Structure

EDFD, Region 15, Demonstration Projects Division is subdivided into the Construction and Maintenance Group and the Engineering and Traffic Operations Group (fig. 1).

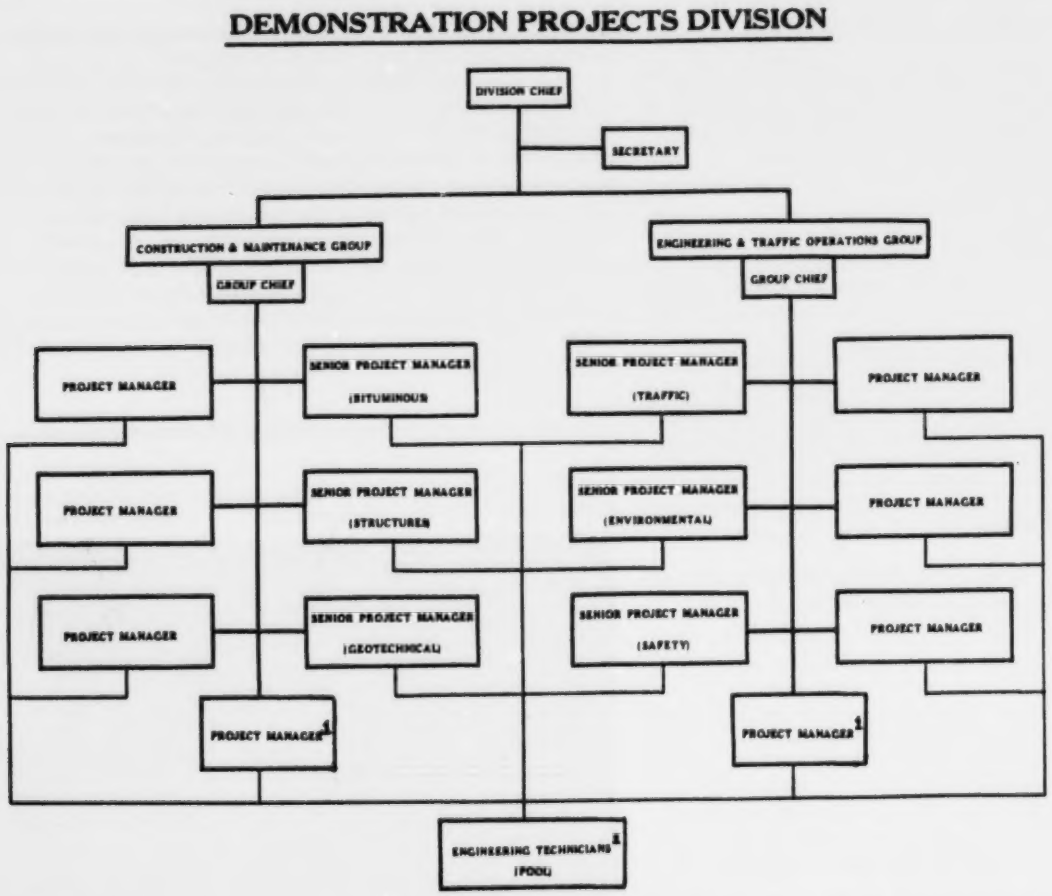
New technology incorporated into the Program is assigned a project name and number. The development, mobilization, and promotion of these projects are assigned to a project manager who generally manages several projects in the same technological area.

In addition to the project managers assigned to the Demonstration Projects Division, personnel with special engineering expertise from other units in EDFD, Region 15, and the Washington, D.C., Headquarters Office are assigned projects to manage as collateral duties. EDFD, Region 15, engineering technicians are assigned to assist in some demonstration projects.

Project Development

A major effort of the Program is to closely monitor potentially promising results of research and

Figure 1.—Demonstration Projects Division.



[1] **Personnel from EDFD or Washington, D.C., Headquarters who are assigned to manage projects as collateral duties.**
[2] **Assigned, as needed, to assist in project mobilization and demonstration.**

development activities that lend themselves to actual onsite demonstrations—promising research items that would require more than written reports to insure ultimate adoption.

Ideas for demonstration projects also are actively solicited from various FHWA offices, State and local highway agencies, and private industry.

When technology with potential for demonstration is identified, a project proposal is prepared. This proposal briefly describes the new technology, the current status of research and implementation efforts, the proposed method of demonstration, the expected benefits, proposed schedules, and estimated funding. The project proposal is circulated for comment to the Interoffice Review Group (IRG, described on page 136 of this issue) (*5*), other FHWA Washington, D.C., Headquarters Offices, and all FHWA Regions. Upon acceptance of the proposal by these offices, a project manager is selected and a technical advisory committee (TAC) is formed. The TAC assists the project manager in the development of the demonstration project, monitors the project mobilization and activity, and keeps the respective program offices informed.

The TAC's generally consist of representatives from the offices included in the IRG and offices having interest or expertise in the particular area, including the Offices of Research, Development, Highway Operations, Engineering, and Environment. Also, if a particular expertise is identified at the State highway or transportation department level, staff is invited to brief the TAC on the particular item and the State's experience. The TAC and project manager then complete a work plan setting forth the objective, scope, and details of the project such as method of demonstration, equipment needed, funds required, and a development and implementation schedule, which is detailed and covers all phases of activities. Assuming all systems are GO, the project is then developed and mobilized.

Kinds of Demonstration

As the Demonstration Projects Program evolved into a nationally accepted medium of technology transfer, three distinct demonstration methods evolved.

Hands-on demonstration

The first method is an on-the-job, "hands-on" demonstration of the use of newly developed equipment and techniques. This method was used to demonstrate projects on air, noise, and water pollution. Several pollution monitoring devices varying in sophistication and price were transported by van

Figure 2.—A demonstration project trailer stationed in an urban environment to demonstrate the use of various equipment to collect, monitor, and forecast levels of air pollution.

around the United States and demonstrated under actual on-the-job conditions to requesting agencies (fig. 2). The vans, in addition to transporting the equipment, served as on-the-job laboratories. Each had on board minicomputers to aid in the rapid processing and analyzing of collected data. Use of these computers also was demonstrated. Because of the demonstrations, agencies could better understand the uses of the pollution monitoring devices and were in a better position to decide the kind and size of equipment to purchase to best suit their needs. Demonstration projects on measurement of pavement skid resistance, urban traffic systems, and hydraulic energy dissipators (fig. 3) also used this hands-on method.

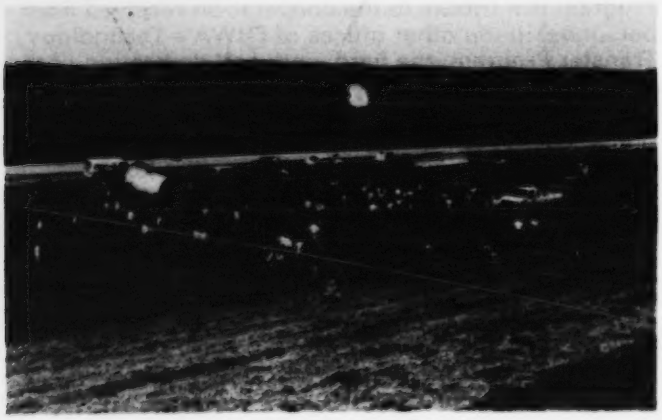
Figure 3.—Demonstration of scour prevention and energy dissipation at culvert outlets with aid of a portable hydraulic flume.

Figure 4.—Project manager conducting a workshop training seminar.

Workshop training seminars

A second demonstration method, workshop training seminars, is conducted on-the-job or in the classroom, depending on the technology involved (fig. 4). An engineer, at times accompanied by engineering technicians, conducts the workshop and training sessions. Demonstration projects on quality assurance using statistical specifications, fiberglass roving for ditch erosion, improved inlets for highway culverts, hydraulic design of energy dissipators, and reduced seasonality of hot plant-mix bituminous paving were conducted as workshop training seminars.

Figure 5.—Attendees at an on-the-job demonstration workshop seminar observing the preparation of "asphalt rubber" before its application on the road.



Pilot demonstration installations

A third demonstration method involves constructing a project incorporating the promoted technology. Technical and financial assistance are provided for the design, construction, and performance evaluation of a pilot demonstration installation. Examples of this method include demonstration projects on open-graded friction courses, asphalt emulsions, sulfur extended asphalt, and the very popular project, recycling of asphalt pavements.

Project Presentations

The number of project presentations—either equipment hands-on demonstrations, workshop training seminars, or pilot demonstration installations—conducted for any agency depends on the need to achieve *Statewide* adoption and implementation of the new technology and the availability of Program funds.

Although it is highly desirable to demonstrate the use of new technology to all State and local highway agencies, limited resources make this impossible. Therefore, when a project is scheduled for presentation, it is recommended that all neighboring highway agencies be invited to attend. To achieve maximum project exposure of new technology being incorporated into a pilot demonstration installation, on-the-job demonstration workshops and seminars are recommended (fig. 5). Highway agencies in the State and in surrounding States can witness firsthand the application and use of the new technology being demonstrated. These demonstration workshops provide a highly efficient and effective means of technology transfer.

All pilot demonstration installations must have performance evaluations. Reports of these evaluations and the construction techniques are valuable to the participating agency and help promote the techniques to other agencies that are skeptical of the new technology.

Program/Project Evaluation

The Demonstration Projects Program was evaluated to support its current and future budgetary requests, improve the data base on which to make program management decisions, and assure that the Program was being effectively administered. This evaluation, completed in 1980, was a coordinated effort between the Demonstration Projects Division and the Administration Division of EDFD, Region 15. (*6*) The evaluation found that the Demonstration Projects Program had been an effective agent for incorporating new technology into the activities of highway transportation departments and recommended that a continuing evaluation process be implemented. The recommendation was implemented in Fiscal Year 1981.

The process requires a short and long term evaluation of each project. A short term evaluation is made when all participants attending a demonstration presentation complete a form. These critiques enable the project manager to fine-tune the presentation to assure a quality delivery process. The long term evaluation, conducted at the completion of each project, measures the effectiveness of the promotional efforts—was the project successful in effecting change?

A second evaluation of the Program was conducted in Fiscal Year 1981 by the FHWA Office of Management Systems as part of a nationwide study on the effectiveness of FHWA's overall Technology Transfer Program. (*7*) This evaluation again concluded that the Demonstration Projects Program had a good reputation and was well received. The one recommendation of the evaluation was that the Demonstration Projects Program should document to the field policy on project participation. This recommendation was implemented in October 1981.[3]

Summary

Since the establishment of the Demonstration Projects Program, many projects have been successfully demonstrated. Because of this Program, several highway agencies now are using newer and better methods to provide a safer, more economical, energy efficient, and environmentally acceptable transportation system.

The adoption and application of demonstrated technologies such as open-graded friction courses, sprinkle mixes, concepts for improving traffic safety through construction and maintenance zones, and urban traffic system improvements have resulted in reducing the number and severity of traffic accidents and highway fatalities.

As highway costs continue to increase, funds must be stretched to meet current needs. One solution to this problem is to use the most efficient and cost-effective methods to design and construct improvements. Demonstration projects responsible for the adoption of such techniques as the Roadway Design System (RDS), Reinforced Earth, hydraulic design of energy dissipators, subsurface investigation, and cathodic protection of bridge decks have contributed to reducing the cost of highway construction.

Efforts to become more energy efficient have been satisfied when demonstrated technologies such as recycling of asphalt pavements, sulfur extended asphalt, and asphalt emulsions have been adopted for use.

Planning, designing, and building highways to be more compatible with the environment have been enhanced by the adoption of demonstrated techniques for estimating, measuring, and abating air, water, and noise pollution.

The Demonstration Projects Program has played a significant role in the adoption in the last decade of much of the new technology. The success of the Program is a tribute to the cooperation received from personnel in the other offices of FHWA's Technology Transfer Program, the hard work and dedication of the personnel assigned to the Demonstration Projects Division and other divisions in EDFD, Region 15, and the personnel in the Region and Division Offices assigned to work with the Program in the field.

[3] D. A. Bernard, Chief, Demonstration Projects Division, memorandum to FHWA field offices, Oct. 26, 1981.

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(2) Administrative Memorandum 1–20, Jan. 8, 1969.

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(4) FHWA Order 1–1, Change 123, item (7), *Federal Highway Administration,* Washington, D.C., Feb. 23, 1981.

(5) "Technology Transfer Program," FHWA Order 6000.1, par. 5(b), *Federal Highway Administration,* Washington, D.C., Sept. 6, 1977.

(6) Demonstration Projects Evaluation Study, *Eastern Direct Federal Division,* August 1980.

(7) Technology Transfer Study, *Federal Highway Administration, Office of Management Systems,* September 1981.

Douglas A. Bernard, Chief, Demonstration Projects Division, joined the Federal Highway Administration in 1962. He served as an area engineer in the District of Columbia and as a highway engineer in the Office of Traffic Operations. His assignment in the Demonstration Projects Program began in 1970 when he served as Chief, Construction and Maintenance Group. Among Mr. Bernard's accomplishments are his influential efforts in the promotion of asphalt pavement recycling.

Additional information on the Demonstration Projects Program and technology transfer can be obtained by contacting

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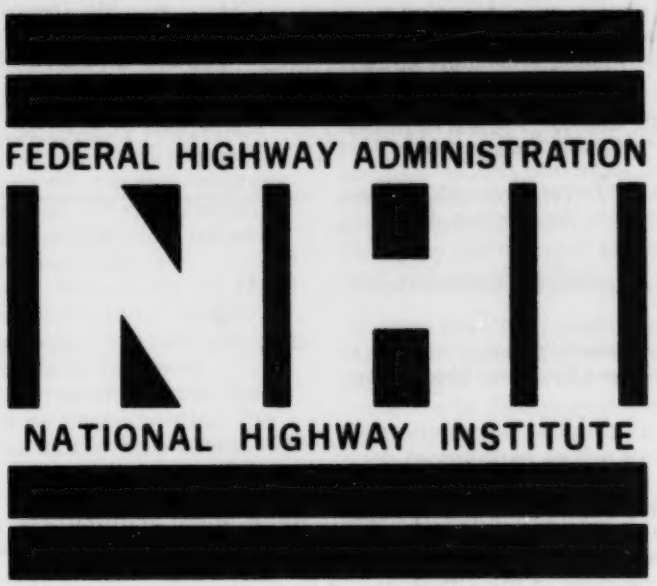
NHI—A Leader in Technology Transfer

by
James P. Iverson, Larry E. Jones, and Albert Tappa



Introduction

Section 115 of the Federal-aid Highway Act of 1970 (23 USC 321) authorized the establishment and operation of the National Highway Institute (NHI). The Act directed that NHI "... develop and administer in cooperation with the State highway departments, training programs of instruction for Federal Highway Administration and State and local highway department employees engaged or to be engaged in Federal-aid highway work. Such programs may include, but not be limited to courses in modern developments, techniques, and procedures relating to highway planning, environmental factors, acquisition of rights-of-way, engineering, construction, maintenance, contract administration, and inspection." (*1*)[1]

The need for a training arm in the Federal Highway Administration (FHWA) had long been recognized. As far back as 1922, the late Thomas H. MacDonald, as head of the Bureau of Public Roads, now FHWA, expressed a desire to establish a Bureau of Public Roads College to keep practicing engineers abreast of the rapid progress being made in the highway engineering field.

The need to train and retrain engineers, technicians, and other support personnel in the highway community continues to be a critical concern. Public demand for safer highways and better operations coupled with higher costs and lower budgets requires our engineers and administrators, now more than ever, to make critical decisions based on current knowledge of new research and technology. This has made training a major element in the technology transfer movement, and it has made training an essential activity for all disciplines within the highway community.

In fulfilling its legislative mission, NHI maintains a direct and continuous relationship with the program offices of FHWA Headquarters, FHWA field offices, State highway agencies, professional organizations, and colleges and universities. In conjunction with the Demonstration Projects Division, Construction and Maintenance Division, and the Implementation Division of FHWA, NHI supports FHWA's technology transfer program through the development of nationwide training programs. The necessary liaison to promote and conduct such training programs is provided by the designated NHI contact in each FHWA Region, Division, and State highway agency.

As a staff office under the FHWA Administrator, NHI is organized into

[1] Italic number in parentheses identifies reference on page 166.

three functional offices—State Programs, University and Industry Programs, and International Visitors Program. The main technology transfer activities of each office are described in the following sections of this article.

State Programs Office

The State Programs Office is responsible, with the assistance of State highway agencies, for identifying current and future training needs and for coordinating with FHWA program and field offices in developing training to satisfy the identified needs. This responsibility was outlined in the 1970 legislation that created NHI and has remained unchanged.

To accomplish its mission, the State Programs Office develops only training courses that are not readily available from consulting firms or educational institutions and courses that State highway agencies would not ordinarily develop for themselves. With this philosophy as a guide, NHI has geared training course offerings toward topics that involve new and rapidly changing technology. These courses frequently are an integral part of FHWA's overall technology transfer effort to communicate the results of recent research and new technology.

Short courses

Training assistance is provided using two basic formats. The first and most familiar is the development and presentation of short courses (usually lasting 1 to 5 days). The Offices of Research and Development play an important role in the initial course development process. More specifically, the Implementation Division in the Office of Development serves as the bridge between research and the practical application of new technology. Assistance provided by the Implementation Division includes the development of training course materials used by NHI in its course presentations. The predominant method of course development and presentation is by private consultants contracted through competitive bidding. A significant number of courses also are developed in-house and presented using FHWA and State highway personnel as well as university staff members as instructors.

Presentations of a course are made available on a first-come-first-serve basis to highway and transportation agencies by 1- or 2-page "Blue Line" course announcements. A Blue Line, which is issued for each course, describes the course in detail and indicates for whom the course is designed, how to request a presentation, and who in NHI to contact for additional information. The Blue Line is distributed to FHWA Headquarters and field offices, State highway agencies, and other interested organizations. In addition to the individual Blue Line course announcements, NHI publishes a special Blue Line that projects the short courses to be available during the next 18 months. This announcement is updated twice a year.

Training courses generally are available for only 1 to 2 years because of other priority training needs and related budget constraints. However, every effort is made to insure that the training demand is reasonably met and distribution of the presentations is adequate. For example, a course funded for only 10 presentations may be offered to the States on a regional basis to insure each has an equal opportunity to attend. Requests from State highway agencies to host a course are submitted to NHI through the local FHWA Division Office. Local agency requests are submitted through the State highway agency before going to FHWA.

In line with its efforts to provide courses for national distribution, the State Programs Office sponsors special training activities such as seminars and courses tailored to local needs. One example is NHI's sponsorship of an effort by FHWA's Region 7 to develop and present several courses on urban drainage design. These presentations proved helpful to many local agencies in Region 7.

During Fiscal Year 1981, NHI offered 62 different courses and made 386 presentations of these courses to 11,800 participants. Approximately 16 percent of the participants were FHWA employees, 61 percent were State, and 23 percent were local and other agency employees. Figures 1 and 2 reflect the growth of course presentations and the number of participants since 1971. The NHI cost to train each participant has continued to drop over the years. In Fiscal Year 1981 the cost was approximately $80 per participant.

One-half of 1 percent funds

The second format for providing training assistance is through the use of "one-half of 1 percent funds." The 1970 Highway Act (23 USC 321(b)) allowed States to use up to one-half of 1 percent of their urban, primary, and secondary system Federal-aid apportionments for the cost of tuition and direct educational expenses in connection with the training of State and local highway agency employees. These funds are limited to 75 percent of the cost of the training and cannot be used for travel, subsistence, or salaries of course participants. (Higher sliding scale rates are available in Public Land States.) To date 28 States have seen fit to use, in varying amounts, the one-half of 1 percent funding option.

The use of these funds can significantly enhance a State's training effort. The program is basically free of redtape and Federal involvement. The Division Administrator in each State is authorized to approve training programs either annually or as each individual training effort is initiated.

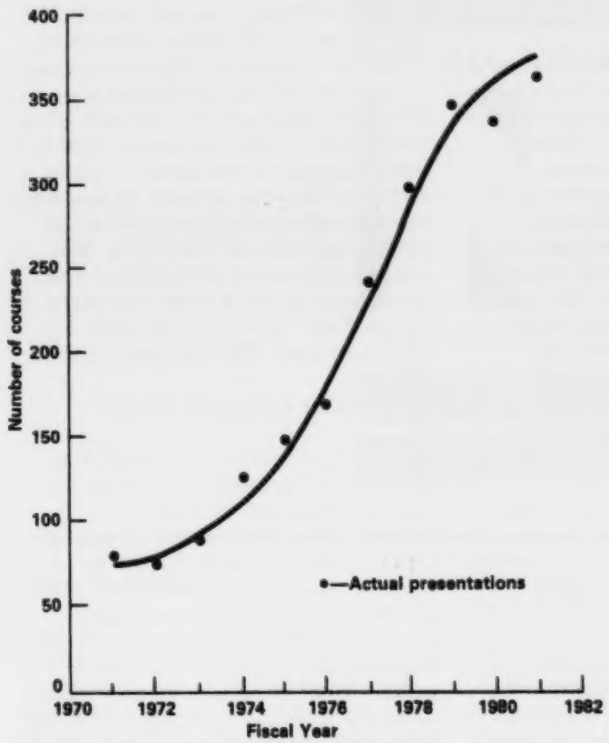


Figure 1.—Growth trend of NHI course presentations per Fiscal Year.

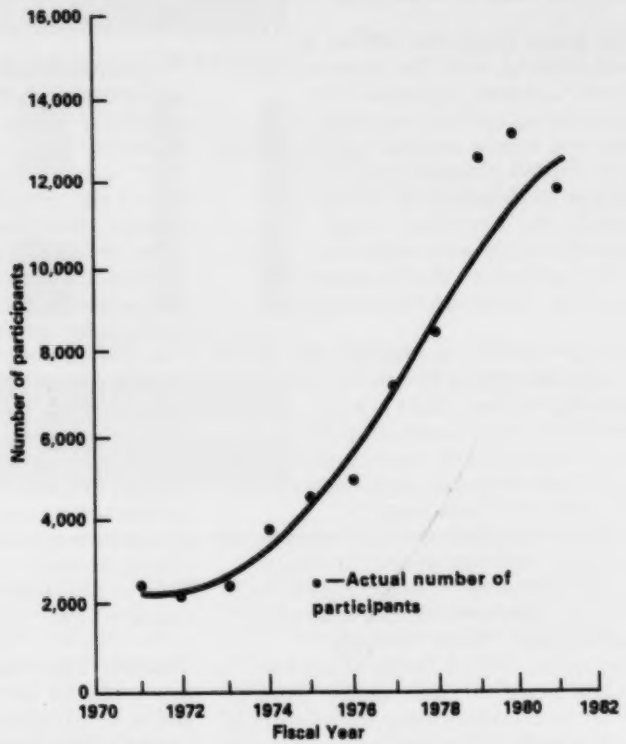


Figure 2.—Growth trends of number of NHI course participants per Fiscal Year.

All of the conventional ways to present training—in-house training, consultant contracts, or public agency agreements—are eligible for Federal funding. Even training equipment that will remain in use by the State is an eligible expense.

Another use of the one-half of 1 percent funds is the purchase from NHI contractors of additional presentations of a given course. At times a State may have a training need that cannot be satisfied by the limited number of presentations available under NHI's contract. When this occurs, the State can obtain the needed training at a very reasonable cost because development costs already have been borne by NHI.

Ongoing and future training

NHI has responded to a variety of training needs since its establishment. In the early and mid-1970's highway agencies were faced with significant budget and staffing cuts, but at the same time more and more Federal and State requirements were being placed on these agencies. The most notable example was the environmental impact legislation. In responding to the training need generated by this legislation, NHI developed a full-scale training effort dealing with various environmental subjects. In recent years the demand for environmental training has been exceeded by such new concerns as inflation, safety, and the desire to better manage the existing transportation system. NHI has responded to these changing needs and offers a number of in-house and contractor instructed courses addressing these topics. Courses in the general areas of construction and maintenance, highway

engineering, planning, safety, traffic operations, environment, right-of-way, and financing are presently available. Some of the more popular courses conducted during Fiscal Year 1981 included Construction Engineering Manpower Management, Design of Urban Streets, Equipment Management Systems, Estimating Highway User Costs, Highway Program Financing, Pavement Management, Practical Applications of Statistical Quality Control, Safety Design and Operational Practices for Streets and Highways, Techniques for Pavement Rehabilitation, and Value Engineering.

Many of the new courses that will become available during Fiscal Year 1982 support FHWA's Program Emphasis Areas—highway safety, cost effectiveness in design and construction, and pavement management. A sampling of course topics to be presented in the near future includes safety evaluation and engineering studies, bridge inspection, design of welded connections, engineering fabrics, traffic signal timing optimization, preconstruction engineering management, construction and rehabilitation of concrete pavements, and traffic network simulation.

University and Industry Programs Office

The University and Industry Programs Office has been heavily involved in technology transfer activities from the time NHI was formed in 1971. In support of NHI's mission, this office promotes technology transfer by working in the following primary areas:

- College curriculum program.
- Lending library.
- Information exchange bulletins.
- Fellowships/scholarships.

One of the most successful technology transfer activities has been the University/FHWA college curriculum program. NHI, acting on a recommendation from the Implementation Division, established this program in October 1975 so that educational materials developed for FHWA-sponsored training courses could be included in the curriculums and short course offerings of technical institutes, colleges, and universities. In the interests of technology transfer and the effective use of Federal funds, this program is intended to extend the benefits that may be derived from dollars already expended to develop training curriculums.

Instructional and student materials from over 40 courses have been made available, and well over 1,000 sets of these materials have been distributed. A recent evaluation of the program revealed that in 1980 alone, the participating schools had used the material to train approximately 6,000 students. Nearly half of these students were employees of highway agencies.

Although the primary target audience of the college curriculum program is schools (over 125 participate in the program), nearly one-third of all requests for material have come from various State and local highway agencies that are conducting their own in-house training activities.

To support the college curriculum program, NHI has attempted to strengthen the working relationship between FHWA, State highway agencies, and the academic community by sponsoring special conferences for college and university faculty, arranging special courses to provide faculty selected curriculum materials, and inviting faculty members to attend NHI course presentations.

It would be impossible to estimate accurately the number of work hours saved in curriculum development as a result of the college curriculum program and its related activities. However, there is little doubt that both the quality and quantity of highway transportation education have improved because of this single aspect of the total FHWA technology transfer effort.

The University and Industry Programs Office operates an audiovisual lending library as an integral part of its overall effort to provide training for employees of Federal, State, and local highway agencies. When new audiovisual materials such as films, slide-tape presentations, and video tapes are developed by the various offices within FHWA, copies are given to NHI for distribution through the lending library. Private organizations also have provided NHI with films and other audiovisual material for distribution through the lending library. Such participation is encouraged by NHI because the diversity of materials available is enhanced. Primary users of the library have been State highway agencies and educational institutions. Approximately 180 titles on various highway transportation topics are available at this time. NHI envisions that the demand for the lending library services will continue to show a steady increase as Federal funds are reduced and highway agencies find it necessary to expand their own training programs.

NHI publishes education and training information exchange bulletins that serve as FHWA's principal means of conveying and exchanging information on various training programs and educational materials related to highway transportation. The bulletins are successful mainly because of the willingness of many others in the highway community, such as highway agencies, trade associations, and educational institutions, to provide information on current technology transfer activities. Materials routinely

announced include short courses, correspondence courses, publications, films, slide-tape presentations, video tapes, and sets of instructional material that may be used by requesting agencies to conduct their own training programs.

The bulletins are distributed to identified contacts in State, city, and county transportation agencies, educational institutions, and private organizations having highway transportation interests. Currently, about 4,000 copies of each issue are distributed. NHI anticipates that these bulletins will serve as an increasingly valuable tool for transferring technology and exchanging information as reduced Federal spending makes it necessary for State and local agencies to do more of their own training.

Another major activity of the University and Industry Programs Office is the administration of a fellowship/scholarship program. This program assists State and local highway agencies in developing needed staff resources through formal education.

An FHWA Notice, issued each September to describe the program and to provide application forms, is distributed to numerous State and local contacts as well as to FHWA offices. The fellowships/scholarships are offered for part-time and full-time study in any discipline needed in the field of highway transportation. Recipients may study at any accredited college or university. To meet the needs of individuals who work in remote locations or who cannot take time away from their jobs to attend regular college classes, scholarships also are offered for correspondence study.

To apply for a fellowship/scholarship, an individual submits the application forms, employer's statement of endorsement, and other supporting information to the local FHWA Division Office for forwarding to NHI for evaluation. Applicants are evaluated by a selection panel representing the highway interests of government, industry, and the academic community. The major factors considered by the selection panel are: the candidate's potential to contribute to a highway agency's transportation program, the objectives of the candidate's study program, relevant experience, and academic and professional achievements. A successful candidate must sign an agreement to work for a public highway transportation agency for a period specified by the kind of award and length of study. For example, a candidate receiving an award for full-time study must agree to work for a period equal to three times the length of the training.

The amount of the award depends on the kind of award, length of study, and level of salary support offered by the employer. The present maximum award is $7,500. Approximately 100 awards were made for study beginning in the fall of 1981.

As a special facet of the fellowship/scholarship program, the University and Industry Programs Office has responded to specialized educational needs of highway agencies by contracting with universities to develop and present intensive graduate level courses on selected topics. Fellowships have been awarded for highway agency employees to attend these courses. Past efforts include the Environmental Management Institute Program at the University of Southern California, the Highway Safety and Traffic Study Program at Northwestern University, and the Public Service Archeology Program at the University of South Carolina. A contract recently was awarded to develop and present a 6-week study program in Pavement Management.

The growth of the fellowship/scholarship program is shown in table 1. Historically, 85 percent of the awards have gone to employees of State agencies, 8 percent to city employees, 5 percent to county employees, and 2 percent to FHWA employees.

NHI recently completed an indepth study of the fellowship/scholarship program. Virtually every FHWA field office and State highway agency participated in this effort. The study confirmed the merits of administering the program at the national level and the significant value of fellowships and scholarships to the continuing education programs of State and local agencies.

International Visitors Program Office

Although seldom thought of in the context of technology transfer, the International Visitors Program is, in fact, one of the prime contributors to the dissemination of highway technology, not only in the United States but internationally as well.

The International Visitors Program provides training and orientation for foreign highway officials and others interested in highway practices in the United States. Annually, NHI develops and conducts academic, on-the-job, or observational training for 400 to 500 international officials. For example, in Fiscal Year 1981, NHI arranged 3,005 workdays of training for 501 road and transportation officials from 52 different countries. Over the past 9 Fiscal Years, programs have been conducted for 4,256 international visitors.

Table 1.—Fellowship/scholarship awards by academic year and program

Academic year	Safety fellowships	Transportation fellowships	Technology scholarships	Environmental Management Institute	Northwestern safety/traffic	Public service archeology	Total
1972–73	12	—	—	—	—	—	12
1973–74	48	22	—	4	—	—	74
1974–75	36	38	56	8	—	—	138
1975–76	42	39	66	9	—	—	156
1976–77	18	43	84	9	—	—	154
1977–78	18	41	73	15	—	—	147
1978–79	19	39	75	15	36	—	184
1979–80	23	39	44	15	19	—	140
1980–81	13	36	58	8	22	10	147
1981–82	11	37	55	—	—	3	106
	240	334	511	83	77	13	1,258

The purpose of the International Visitors Program is twofold: First, it enables top-level highway officials and other highway professionals to receive indepth exposure to the United States; second, and equally important, it enables these professionals to meet and exchange ideas with American colleagues, observe methods and practices, study at academic institutions, and develop the networks of communication that will mean lasting personal and professional ties transcending national barriers. Because the bulk of the training and orientation is conducted at various State highway and transportation departments, technology transfer becomes a two-way street at the grass roots level between international visitors and State engineers, enriching both equally.

Requests for training are made or referred to NHI by organizations such as the U.S. State Department, the Agency for International Development (AID), the United Nations, the World Bank, the International Road Federation (IRF), Foreign Ministries of Transport, various foreign embassies, foreign road and transportation organizations, and by numerous individual engineers wanting to upgrade their own expertise.

The International Visitors Program Office maintains contact with officials in Federal and State highway transportation agencies, local governments, universities, and the private sector to place visitors where their study or training goals best can be met. The visitors generally are interested in such functional areas as:

- Highway planning, design, construction, and maintenance.
- Highway right-of-way and environmental policies.
- Aerial surveys (photogrammetry).
- Bridge design, construction, inspection, and maintenance.
- Laboratory practices and research in structures, materials, and traffic systems.
- Traffic engineering and operations.
- Highway and motor carrier safety.
- Highway financing and administration, including toll roads.
- Highway equipment maintenance, repair, and use.

Requests for training are evaluated and programs are arranged to meet the participant's individual needs. Programs range from 1 day to 1 year or more and may include both university and field training. Field training is provided by FHWA, State highway agencies, and the private sector at no cost to the participant. Costs for university tuition, international and domestic travel, and subsistence are borne by the foreign governments or the sponsoring agencies, such as AID or IRF.

Outlook

NHI strives to identify and respond to current and evolving training needs. During the past year, priorities have been studied and programs adjusted to best match the aims of FHWA, with close

attention to the national emphasis areas. The following guidelines that illustrate the direction NHI will be taking in the near future were developed from internal reviews.

1. NHI will continue to work closely with field offices and State highway agencies to achieve better understanding of and respond to national needs.

2. Greater efforts will be made to deliver the most cost-effective training. Increased use of the "train-the-trainer" approach is anticipated as well as increased use of FHWA's valuable resource of in-house talent to present NHI-sponsored training courses.

3. Greater use of one-half of 1 percent training funds will be encouraged to complement other State training efforts.

4. More fellowship/scholarship funds will be used to provide educational assistance in areas of study consistent with national emphasis areas, such as safety, pavement management, and value engineering.

5. NHI will seek ways of providing additional low-cost, high-yield technological assistance to the highway transportation community by distributing and loaning training materials at no cost to State and local agencies and college faculty, involving college faculty in NHI-sponsored training courses where possible, and encouraging private industry and universities to develop and conduct highway transportation training courses.

6. NHI will increase its technology transfer efforts under the International Visitors Program by expanding its services to members of the international highway/transportation community who attend government/industry-sponsored meetings and conferences in the United States.

REFERENCE

(1) Public Law 91–605, *91st Congress*, Sec. 115(a), p. 10, Dec. 31, 1970.

James P. Iverson is a highway engineer with the State Programs Office of the National Highway Institute, Federal Highway Administration. Mr. Iverson manages NHI-sponsored training programs in design, construction, maintenance, and other engineering areas. Prior to his present position, he served as a safety engineer in the Office of Highway Safety, a community planner in the Office of Environmental Policy, and as the environmental coordinator in the FHWA Florida Division Office.

Larry E. Jones is a training officer in the University and Industry Programs Office of the National Highway Institute, Federal Highway Administration. Mr. Jones manages contracts with educational institutions for development and presentation of specialized training programs. He also manages NHI's program for providing FHWA-developed curriculum materials to college and university faculty. Prior to his present position, he served overseas for 9 years as the training officer for the FHWA Division Office in Laos.

Albert Tappa is the International Programs Officer in the National Highway Institute, Federal Highway Administration. He joined FHWA in 1967 after serving as a career officer in the United States Army in World War II and the Korean and Vietnamese conflicts. During his military service, he lived in or visited some 35 different countries in the performance of his military intelligence duties. Prior to his present position, he worked as a personnel staffing specialist in the Office of Personnel and Training.

Additional information on NHI and technology transfer can be obtained by contacting the FHWA Regional Offices (see page 178) or

Mr. George M. Shrieves
Director, National Highway Institute
(HHI–1)
Federal Highway Administration
Washington, D.C. 20590

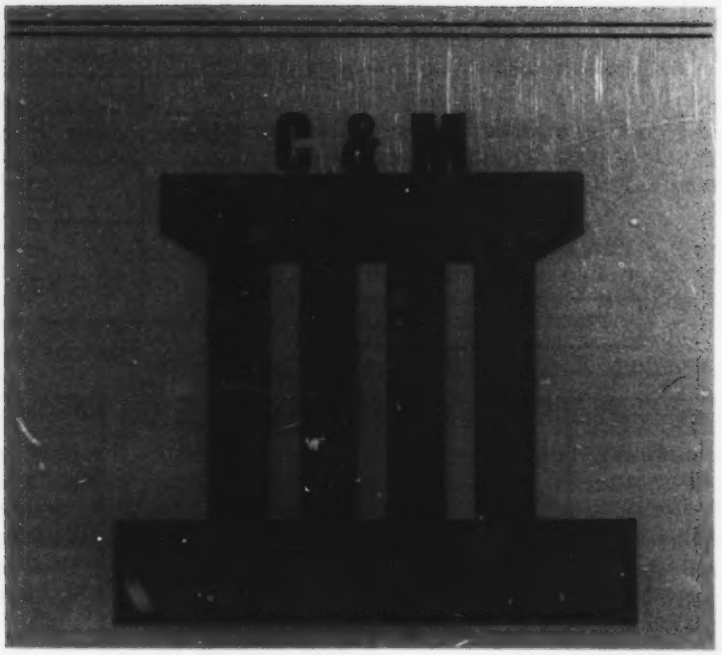
Experimental Projects Program

by

Paul E. Cunningham,

Roger Goughnour,

and Ed Jastremski



Introduction

The Experimental Projects Program administered by the Experimental Projects Branch is under the jurisdiction of the Construction and Maintenance Division, Office of Highway Operations, Federal Highway Administration (FHWA). Performance and cost effectiveness of experimental features are evaluated. National Experimental and Evaluation Program (NEEP) projects and Non-NEEP projects are part of the Experimental Projects Program.

The Experimental Projects Program provides technology and data flow through FHWA technical advisories, NEEP progress reports, national experimental projects tabulations, and construction and material specifications formulation.

In its simplest form, the Experimental Projects Program involves field trials of ideas, methods, practices, or products from any source and evaluates projects whenever economic or cost effectiveness data are desired to respond to highway needs and provide a service to field offices, States, operating units within the Washington, D.C., Headquarters, and local governments.

Background

Originally, the Experimental Projects Program was identified with the Office of Research (1959), with coordination of the Program the prime responsibility of the Office of Engineering. In 1962, the Program was completely placed within the Office of Research, but in 1968, prime responsibility for the Program was returned to the Associate Administrator for Engineering and Traffic Operations. The Program was subsequently reevaluated and revised to reflect updated requirements and criteria, simplifying the administration of experimental features on construction projects and emphasizing the implementation of research findings through this Program. NEEP and the Regional Evaluation Action Program (REAP) resulted as special categories of experimental projects from this reorganized Experimental Projects Program.

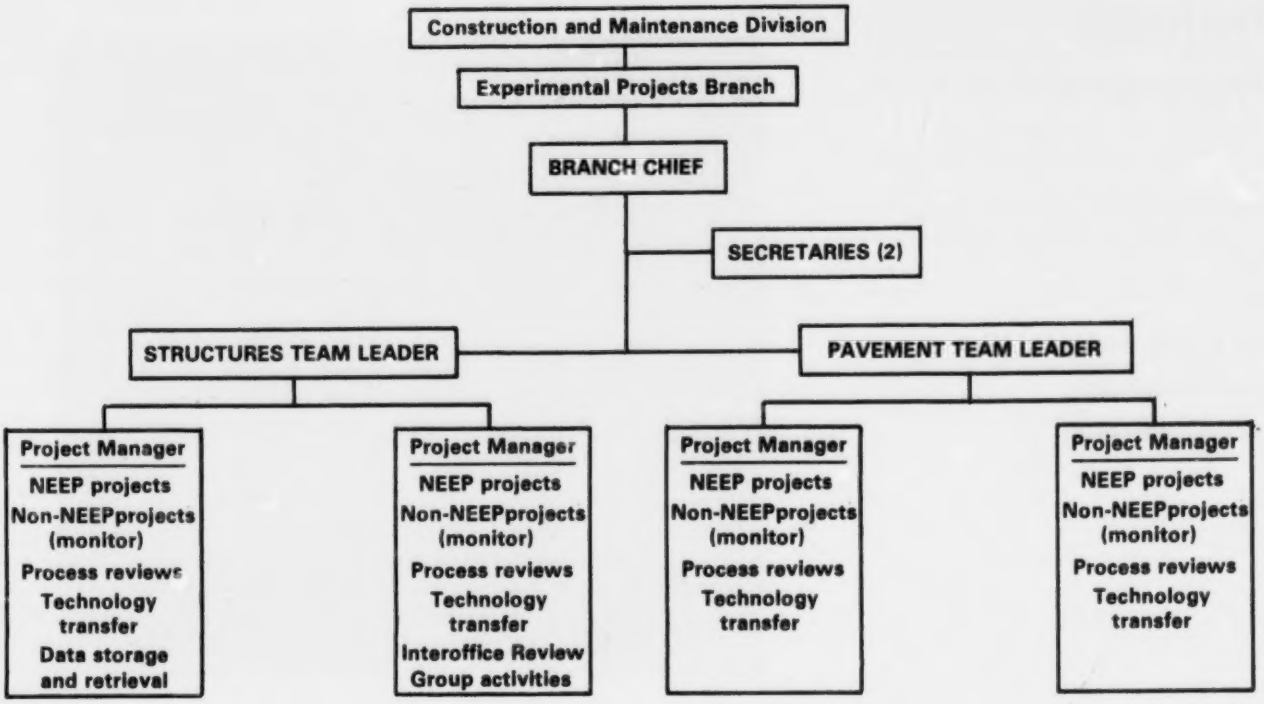


Figure 1.—Experimental Projects Branch organizational structure.

Organization

The Experimental Projects Branch is structured to flexibility and diversification to meet present and future needs. Functions are defined within a Structures section and a Pavement section, with a team leader in each section (fig. 1). Technology transfer activities have been identified as a primary responsibility of the Branch.

Experimental Projects

The purpose of the Experimental Projects Program is to determine if previously researched, field-tested, or documented materials, techniques, or equipment can be adopted for standard use in highway construction. Experimental features are incorporated in Federal-aid highway construction projects to determine the suitability of the features as regular construction items. *(1)*[1]

Work plans, implementation guidelines, and field evaluations performed in a relatively short period determine the merits of the experimental feature, which can be positive or negative, or recommendations can be made. Results are distributed nationally to avoid duplication of effort and provide information beneficial to all interested parties. Experimental feature results serve as a means to incorporate the results into State specifications, standards, or other documents.

Routine experimental projects generally are evaluated visually, and minimum paperwork is required. Projects associated with the Highway Planning and Research Program (HP&R) involve more sophisticated evaluations, including instrumentation and analysis

[1] Italic number in parentheses identifies reference on page 172.

procedures. HP&R projects provide new field evaluations where needed and promote verification of promising research findings. During construction, the need for additional research on highway methods and materials often becomes evident.

When an HP&R study, Implementation Division activity, or an Eastern Direct Federal Division (EDFD) demonstration project is involved with an experimental project, the work is coordinated with the Offices of Research and Development and EDFD.

NEEP Projects

This program is designed to encourage the construction of particularly promising experimental features through the evaluation of existing products, methods, or practices on Federal-aid construction projects. FHWA Regions generally are asked to encourage at least one State in each Region to participate in the evaluation program. NEEP projects are expected to have broad or national application. These high interest or high priority national emphasis area projects are conducted over a short period, usually 2 to 3 years. NEEP is managed by the Experimental Projects Branch.

The following general plan is used to focus efforts on NEEP projects.

1. Preliminary evaluation made of an experimental feature—promising results of research or new products, methods, or procedures.

2. Washington, D.C., Headquarters FHWA technical advisory committee established to further evaluate the experimental feature.

3. Project prospectus with test and evaluation parameters developed for issuance to FHWA field offices.

4. Memorandum sent to the field with prospectus guidelines encouraging one or several States in each Region to establish a NEEP project or projects of limited extent.

5. Reports on NEEP project forwarded to the Office of Highway Operations for overall national coordination and analyzed by the Headquarters technical advisory committee.

6. Status reports issued on all NEEP projects.

7. Final summary reports prepared on each NEEP project by the Office of Highway Operations, with the assistance of other appropriate FHWA offices. These reports include conclusions and recommendations so that all States can profit from the national evaluation, whether they participated in the experiment or not.

In all programs, work plans or guidelines are prepared for the particular experiment. Participating States are encouraged to follow the basic work plan to obtain a simultaneous review in an attempt to evaluate an experimental feature under close, similar conditions over approximately 2 years.

The status of current NEEP projects is shown in table 1.

Table 1.—Current NEEP projects

Project No.	Title	Project status
10	Reducing Reflective Cracking in Bituminous Overlays	Final report in preparation
12	Bridge Deck Protective Systems	Continuing evaluation
16	Epoxy Coated Reinforcing Steel	Continuing evaluation
17	Evaluation of Breakaway Cable Terminal for Roadside Guardrail With Other Guardrail Terminals	Final report in preparation
18	Cathodic Protection on Bridge Decks	Continuing evaluation
20	Experimental Pavement Construction Using Econocrete	Final report in preparation
21	Noise Insulation of Private Dwellings	Final report in preparation
22	Pavement Recycling	Project active
23	Highway Advisory Radio	Project active
24	Use of Incentives and Disincentives	Project active
25	Concrete Overlays	Project active
26	Use of Sulfur as an Extender to Asphalt Binder in Highway Construction	Project active
27	Portland Cement Concrete Pavement (PCCP) Joint Restoration and Rehabilitation	Project active
28	Pavement Drainage	Project active

Currently planned NEEP projects include:

NEEP No. 29—Rapid Testing Procedures on Bridges.
NEEP No. 30—Application of Fabrics in Highway Construction.
NEEP No. 31—The Evaluation of Prestressed Precast Concrete Deck Forms.
NEEP No. 32—Alternate Bidding Procedures for Pavement Type Selection.
NEEP No. 33—Epoxy Thermoplastic Pavement Markings.

REAP Projects

This program is similar in intent to NEEP except that it encompasses a regional effort and is designed to evaluate experimental and demonstration features or existing methods and practices that may be unique to a particular Region. REAP projects fall in the broad category of Non-NEEP projects.

The Experimental Projects Branch responsibilities for Non-NEEP projects include:

- Serving as the coordinating office for all policy decisions regarding acceptance or rejection of experimental features.
- Providing assistance to FHWA Regional Offices on management of the Experimental Program to increase the efficiency and effectiveness of the Program.
- Operating the experimental data storage and retrieval system.

Approvals

Procedures in the Experimental Projects Program have been simplified to the maximum extent. As an example, the FHWA Division Administrator has the authority to approve all experimental projects. (*1*) The Division Administrator also can terminate the projects at any time it is determined that the evaluation goals have been achieved.

Reports

Reports for experimental features can be obtained by any means acceptable to the Division Administrator. In some field offices, the requirements are met by additional comments on the construction inspection report and also the completion of FHWA Form 1461 "Experimental Project Report" (fig. 2). This form is completed annually and forwarded to the Experimental Projects Branch in Washington, D.C., Headquarters for subsequent inclusion in the computerized data file. Two of the Branch's major efforts have been the development of a computerized file for experimental data and annual publication of the "National Experimental Projects Tabulation," which includes a summary of the experimental data on the computer file and provides the mechanism for the dissemination of information to State and local transportation agencies. The computerized data file includes 1,900 experimental projects, including the evaluation of more than 200 construction products. Data files are updated annually with the submission of FHWA Form 1461.

The benefits of an effective evaluation of experimental features are recognized, and the dissemination of this information to interested parties is important. To accomplish this task more effectively, the data storage and retrieval system will be used to identify active experimental applications at the local level. These data eventually will be summarized and distributed to all interested parties.

Technology Transfer

The Experimental Projects Branch provides staff support for the Interoffice Review Group (IRG, described on page 136 of this issue) through the IRG Newsletter, correspondence, summaries, minutes of meetings, permanent secretary responsibilities, coordination of reports, and statements and support to several transportation associations. Planned technology transfer activities include:

- Developing a slide and oral presentation that describes the functions and activities of the Experimental Projects Branch.
- Developing a plan to more effectively evaluate experimental features incorporated in Federal-aid projects.
- Gathering specific cost and performance data on fast-setting concretes, emulsions, fly ash, sprinkle treatments, and glare screens.
- Coordinating activities with the Transportation Research Board, the National Cooperative Highway Research Program, the American Association of State Highway and Transportation Officials, the American Road and Transportation Builders Association, the Association of General Contractors, the National Highway Institute, the Implementation Division, and the Demonstration Projects Division.

RCS HHO-30-19

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT

EXPERIMENTAL PROJECT NO. [1] STATE YEAR NUMBER SUF.

CONSTRUCTION PROJ. NO. [8]

LOCATION [28]

EVALUATION FUNDING [48]
1 ☐ HP&R 3 ☐ DEMONSTRATION
2 ☐ CONSTRUCTION 4 ☐ IMPLEMENTATION

NEEP NO. [49]

PROPRIETARY FEATURE? [51]
☐ YES ☐ NO

SHORT TITLE

TITLE [52]

THIS FORM

DATE [140] MO. YR.

REPORTING [144]
1 ☐ INITIAL 2 ☐ ANNUAL 3 ☐ FINAL

KEY WORDS

KEY WORD 1 [145]

KEY WORD 2 [167]

KEY WORD 3 [189]

KEY WORD 4 [211]

UNIQUE WORD [233]

PROPRIETARY FEATURE NAME [255]

CHRONOLOGY

Date Work Plan Approved: [277] MO. YR.

Date Feature Constructed: [281] MO. YR.

Evaluation Scheduled Until: [285] MO. YR.

Evaluation Extended Until: [289] MO. YR.

Date Evaluation Terminated: [293] MO. YR.

QUANTITY AND COST

QUANTITY OF UNITS *(Rounded to whole numbers)* [297]

UNITS [305]
1 ☐ LIN. FT. 5 ☐ TON
2 ☐ S.Y. 6 ☐ LBS.
3 ☐ S.Y.-IN. 7 ☐ EACH
4 ☐ C.Y. 8 ☐ LUMP SUM

UNIT COST *(Dollars, Cents)* [306]

AVAILABLE EVALUATION REPORTS

☐ CONSTRUCTION [313] ☐ PERFORMANCE ☐ FINAL

EVALUATION

CONSTRUCTION PROBLEMS [318]
1 ☐ NONE
2 ☐ SLIGHT
3 ☐ MODERATE
4 ☐ SIGNIFICANT
5 ☐ SEVERE

PERFORMANCE [319]
1 ☐ EXCELLENT
2 ☐ GOOD
3 ☐ SATISFACTORY
4 ☐ MARGINAL
5 ☐ UNSATISFACTORY

APPLICATION

[320]
1 ☐ ADOPTED AS PRIMARY STD. 4 ☐ PENDING
2 ☐ PERMITTED ALTERNATIVE 5 ☐ REJECTED
3 ☐ ADOPTED CONDITIONALLY 6 ☐ NOT CONSTRUCTED

(Explain in Remarks if 3, 4, 5, or 6 is checked)

REMARKS

[321]

[700]

FORM FHWA 1461 (REV. 8-79) Previous Editions are Obsolete

Figure 2.—Experimental Project Report, FHWA Form 1461.

REFERENCE

(1) "Federal-aid Highway Program Manual," Vol. 6, Chap. 4, Sec. 2, Subsec. 4, *Federal Highway Administration,* Washington, D.C., Mar. 14, 1980.

Paul E. Cunningham is Chief, Construction and Maintenance Division in FHWA's Office of Highway Operations. He began his FHWA career as a highway engineer trainee and over the years has served as an area engineer, highway engineer, maintenance management specialist, and a branch chief. Mr. Cunningham's principal field of interest is in highway maintenance.

Roger Goughnour is Chief, Experimental Projects Branch, Construction and Maintenance Division in FHWA's Office of Highway Operations. His career with FHWA has included positions as a highway research engineer, a materials engineer, and a geotechnical engineer.

Ed Jastremski is a highway engineer in the Construction and Maintenance Division in FHWA's Office of Highway Operations. He has been involved in the construction and design of highways and structures while with the Maryland Department of Highways, Baltimore County Public Works, and private industry. He started his career with FHWA as an area engineer in Maryland and subsequently transferred to the Washington, D.C., Headquarters Office. Mr. Jastremski is permanent Secretary of the Interoffice Review Group within FHWA's Technology Transfer Program.

Additional information on the Experimental Projects Program and technology transfer can be obtained by contacting the FHWA Regional Offices (see page 178) or

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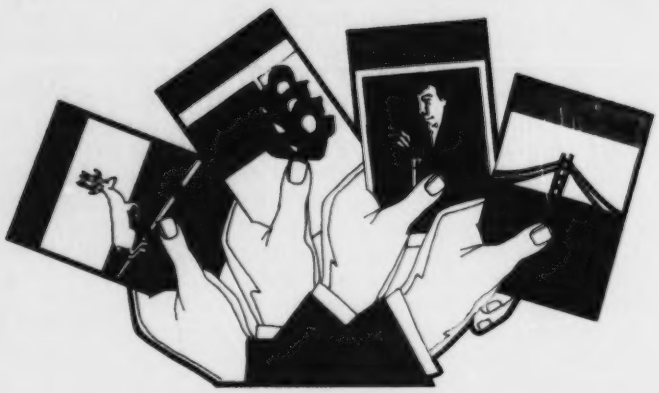
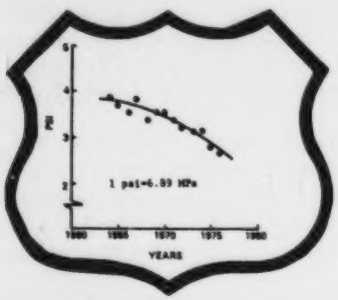
(HHO–30)
Federal Highway Administration
Washington, D.C. 20590



Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Office of Research, Federal Highway Administration, which includes the Structures and Applied Mechanics Division, Materials Division, Traffic Systems Division, and Environmental Division. The reports are available from the address noted at the end of each description.



Pavement Condition Measurement Needs and Methods: Executive Summary, Report No. FHWA–RD–79–67 and Final Report, Report No. FHWA–RD–79–68

by FHWA Structures and Applied Mechanics Division

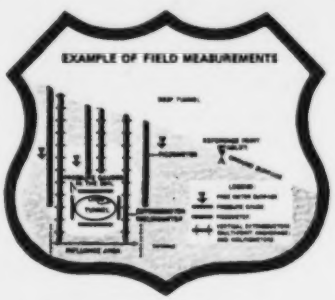
Many State transportation agencies are using highway pavement management systems when making pavement maintenance and rehabilitation decisions. Accurate, current pavement condition data are necessary inputs to an effective pavement management system. For this research study a field review was made of the pavement condition evaluation practices followed in 11 representative State highway and transportation agencies. Each of the selected agencies had instituted a program for making field measurements of pavement condition to be used for scheduling pavement maintenance and rehabilitation. The results of the field reviews documented in these reports show ways that pavement condition evaluation methods vary between States and regions.

The reports treat the four categories of pavement condition data—friction, roughness, structural capacity, and distress. Each category is examined for the type, format, and extent of field measurements required to develop the desired pavement condition data; the various kinds of measurement equipment available and the applications of each; and field data reduction, storage, retrieval, and manipulation methods.

The reports present evaluations of the more widely used measures of the structural capacity of an inservice pavement including load bearing, static deflection, dynamic deflection, impact, and wave propagation. Pavement roughness measuring equipment discussed in the reports includes the direct profiling devices and those devices that provide a "filtered" measure of pavement roughness.

For an optimum pavement condition evaluation system, the reports describe the parameters to be measured, the field procedures to be followed, the preferred equipment for field use, and both the manual and the automated data processing and evaluation methods.

The reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 80 101785 and PB 80 101793).



Representative Ground Parameters for Structural Analysis of Tunnels: Vol. 2, In Situ Testing Techniques, Report No. FHWA/RD–80/013

by FHWA Structures and Applied Mechanics Division

Preliminary subsurface investigations at new tunnel sites allow predictions to be made of the

ground response to the presence of the tunnel opening during and after construction. Ground behavior considerations include the stability of unsupported ground, short term and long term loadings on tunnel supports and tunnel linings, and ground water movement to the tunnel opening.

This report presents a general methodology for subsurface site investigation and evaluates the available in situ field tests for measuring soil or rock properties by geophysical methods. Direct measurement devices and tests applicable in a soil medium include the standard penetration test, cone penetrometer, pressuremeter, vane shear, borehole shear, and the pore water pressure measuring piezometer. Geophysical tests and devices that are useful in a rock medium include the cable jack test, stress relief methods, calipers, dilatometers, and borehole cameras. Indirect geophysical methods described in the report include seismic, resistivity, and magnetic techniques. Large-scale soil and rock testing methods covered in the report are plate bearing tests and direct shear tests. Also provided is a discussion of commonly used drilling and sampling methods that involve larger openings such as shafts, test pits, and pilot bores. Finally, the report describes geophysical engineering classification systems and correlations of soil and rock properties as related to underground design and construction. Included is a review of rock classification methods and their application to the design of primary tunnel supports. Special attention is given to the problems associated with the determination of geotechnical material properties in soil-rock transition zones.

Subsurface site investigations indirectly indicate ground behavior during and after tunnel construction. The distribution of ground materials and the in situ test results, supplemented by visual observations, allow the properties of the ground mass to be estimated. Ground behavior is then predicted on the basis of this information and past experience. Because design and construction in underground space may interact as the tunnel heading progresses, the observed and measured subsurface information is useful for both.

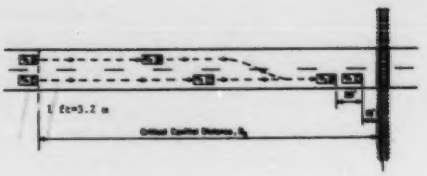
The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 122038).

Planning and Scheduling Work Zone Traffic Control, Report No. FHWA/RD–81/049

by FHWA Traffic Systems Division

Road construction and maintenance activities often lead to significant disruption of traffic flow. This study developed a planning procedure that highway agencies can use to select objectively the most effective work zone traffic control strategy for a given kind of construction/maintenance activity. From existing data and data collected for this study, quantitative procedures were developed for estimating accidents, delays, stops, fuel consumption, operating costs, air pollution, and cost of traffic control.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 242554).



No-Passing Zone Treatments for Special Geometric and Traffic Operational Situations, Report No. FHWA/RD–81/093

by FHWA Traffic Systems Division

Guidelines for the application of no-passing zone treatments on two-lane rural roads are suggested for intersections, railroad grade crossings, narrow bridges, school zones, developed roadside areas, and transitional sections between two-lane and divided highways. This report contains the results of a limited pilot field test of experimental markings consisting of an advanced dotted line prior to the solid no-passing line to warn passing drivers to return to the right lane before the solid line is reached. Also, the pilot field study tested the NO-PASSING ZONE pennant signs.

Limited copies of the report are available from the Traffic Systems Division, HRS–30, Federal Highway Administration, Washington, D.C. 20590.

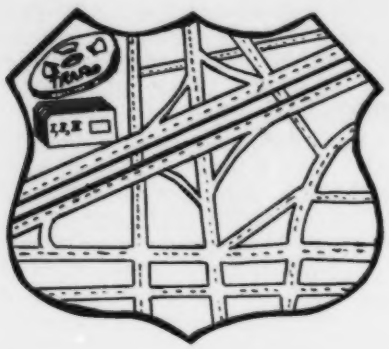
Macroscopic Simulation for Urban Traffic Management: Vol. 1, Executive Summary, Report No. FHWA/RD–80/113 and Vol. 2, TRAFLO User Guide, Report No. FHWA/RD–80/114

by FHWA Traffic Systems Division

The TRAFLO system of models simulates traffic on urban networks and freeways by macroscopic techniques. The TRAFLO system consists of a macroscopic urban

network model called NETFLO, a macroscopic freeway model called FREFLO, and a traffic assignment model. These reports describe the system and provide guidance on its use.

The TRAFLO system allows the representation of traffic in entire urban corridors. This capability provides traffic engineers and planners with a tool for testing and evaluating traffic management strategies that affect sizable portions of an urban street system, including freeways.



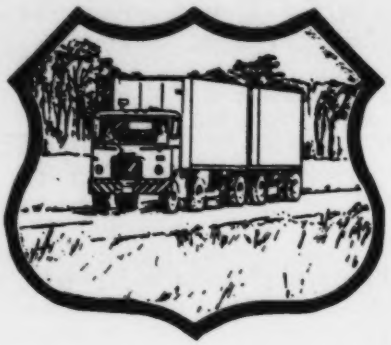
Limited copies of the reports are available from the Traffic Systems Division, HRS–31, Federal Highway Administration, Washington, D.C. 20590.

The Effect of Truck Size and Weight on Accident Experience and Traffic Operations, Vols. I–III, Report Nos. FHWA/RD–80/135–137

by FHWA Environmental Division

These reports document a 5-year study of the accident rates of trucks of various sizes, weights, and configurations as well as the traffic operational impacts of these trucks.

In the accident portion of the study, detailed accident data and matching exposure data were collected at 78 road segments in 6 States. Accident rates were then calculated and compared to assess the relative safety of various trucks.



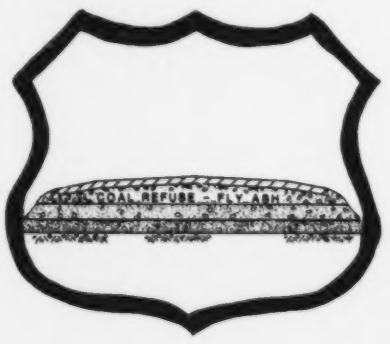
In the traffic portion of the study, 14 sites were selected and instrumented to measure various traffic flow parameters such as speed, acceleration, delay, and closure rate. With this instrumentation, significant differences in traffic flow measures of effectiveness resulting from trucks in the stream were determined as a function of truck size and weight.

Limited copies of the reports are available from the Environmental Division, HRS–43, Federal Highway Administration, Washington, D.C. 20590.

Investigation of the Use of Coal Refuse-Fly Ash Compositions as Highway Base Course Material, Report No. FHWA/RD–80/129

by FHWA Materials Division

The need to recycle waste products is becoming more crucial as the cost of their disposal escalates and the availability of conventional materials becomes scarce. Two such byproducts of the coal industry—coal refuse and fly ash—have shown promise as construction materials. Because of the projected shift from oil to coal for electric power generation, the already abundant supply of both coal refuse and fly ash is expected to increase along with their disposal cost.



This report outlines the findings of a study of the use of coal refuse-fly ash compositions as highway base course material. It includes a discussion of the results from an extensive laboratory testing program on the physical and engineering properties of mixtures of these waste products and a comparison of serviceability index and physical damage parameters based on the VESYS Predictive Design Procedure between crushed stone and coal refuse-fly ash compositions. These findings indicate that substituting stabilized coal refuse-fly ash blends in place of conventional base course material is technically and economically feasible. Inservice use of these stabilized mixtures should now be verified by appropriate field testing. The report also presents procedures for developing design mixes and conducting field tests of coal refuse-fly ash base course material.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 101940).

Field Study of Pile Group Action, Report No. FHWA/RD–81/002

by FHWA Materials Division

This is the final report for a study involving the static vertical load testing of a full-scale, instrumented pile group. The test group consisted of nine pipe piles instrumented for settlement, load transfer, pore pressures, total pressures, and inclination. Two similarly instrumented reference (control)

piles also were installed. Two smaller subgroups within the main group also were tested, and uplift tests were conducted on several of the individual piles. The soils at the test site consisted of clays that were overconsolidated by desiccation. Settlement ratios in the working load range varied from about 1.2 to 1.7, depending on the number of piles that were loaded. Failure was observed by plunging of the individual piles. Unit side load transfer varied essentially linearly with depth. Some dependence of load transfer patterns on residual stresses that remained after driving the piles was observed. The measured behavior of the group and subgroups was modeled by the "hybrid" algorithm and by Program PILGP1, which was developed for this study and documented in the Appendixes (Report Nos. FHWA/RD–81/003–008). Computed and measured results agreed when the unit load transfer curves from the reference piles were used and when the soil modulus of deformation was appropriately adjusted to account for pile reinforcement of the soil and the presence of very small strains in the mass of soil around the group.

A description of the mathematical model, the rationale for its selection, and a prior analysis of group behavior is presented in the Interim Report (Report No. FHWA/RD–81/001). An analysis of dynamic measurements taken during driving the 11 test piles is found in Report No. FHWA/RD–81/009.

Limited copies of the reports are available from the Materials Division, HRS–21, Federal Highway Administration, Washington, D.C. 20590.

Environmental and Safety Aspects of the Use of Sulfur in Highway Pavements, Vol. I—Evaluation of Environmental and Safety Hazards, Vol. II—Field Evaluation Plan, and Vol. III—Annotated Bibliography, Report Nos. FHWA/RD–80/191–193

by FHWA Materials Division

The use of sulfur in highway paving mixtures has introduced questions about the possible pollutants that may be generated, their environmental impact, and the safety aspects associated with mix preparation and placement. This report presents the results of an investigation in which these factors were assessed.

The study considered the safety and environmental aspects of storage and handling, formulation, construction, operation, and maintenance of highway pavements containing sulfur. These considerations included possible evolution of toxic and obnoxious fumes, dusts, and runoffs. Results of tests simulating inservice conditions such as traffic wear, skidding, freeze thaw, spills, and fires also are discussed. The effects of any emissions on humans, soils, highway structural materials, ground waters, and vegetation are presented. Along with the laboratory study, a detailed work plan that discussed methods and equipment for monitoring potential emissions and recommended safety practices was generated and can be found in Volume II. An annotated bibliography dealing with the safety and environmental effects of sulfur-modified paving materials was also prepared (Volume III).

Limited copies of the reports are available from the Materials Division, HRS–23, Federal Highway Administration, Washington, D.C. 20590.

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items that have been recently completed by State and Federal highway units in cooperation with the Implementation Division, Office of Development, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies.

U.S. Department of Transportation
Federal Highway Administration
Office of Development
Implementation Division (HDV–20)
Washington, D.C. 20590

Items available from the Implementation Division can be obtained by including a self-addressed mailing label with the request.

Evaluation of Retroreflective Measurement Devices, Summary Report (Report No. FHWA–TS–81–212) and Final Report (Report No. FHWA–TS–81–213)

by FHWA Implementation Division

These reports document a study to identify and evaluate devices that measure the retroreflectance of pavement traffic stripes under daylight conditions in the field. Four instruments were identified and evaluated. The study recommends that a new instrument incorporating characteristics of each of the tested devices should be developed.

Limited copies of the reports are available from the Implementation Division.

Field Trial With Sulphur-Extended-Asphalt (SEA) Binders, Port Authority of New York and New Jersey, Design and Construction Report, Report No. FHWA–TS–81–207

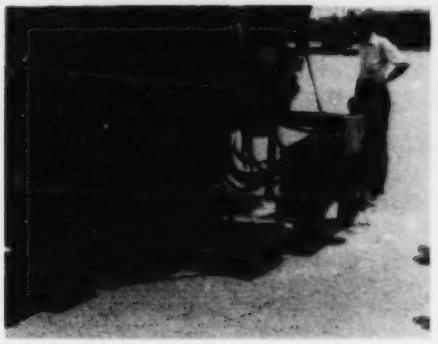
by FHWA Implementation Division

This report is part of a series of reports that describe the procedures and testing used during the design and construction of SEA trial sections. This report examines the feasibility of using SEA binder for roadway pavements. SEA pavement was placed on three cargo area roadways at the Port Authority of New York and New Jersey's John F. Kennedy International Airport. The SEA binder was formulated by separately introducing the asphalt and sulphur to the batch plant's weigh bucket and then mixing in the pugmill with the aggregate (direct mixing). The sulphur/asphalt weight ratio was 30/70.

Limited copies of the report are available from the Implementation Division.

Reflective Marker Paint Stripe Skipper Instruments, Report No. FHWA–TS–81–205

by FHWA Implementation Division



This report summarizes information on the design and testing of two instruments developed by the California and Ohio Departments of Transportation to avoid painting over reflective raised pavement markers. The California instrument optically scans the roadway for reflective surfaces; the Ohio instrument consists of a mine detector type metal sensor to denote the presence of a marker. Both instruments automatically cut off the flow of paint in front of a marker and turn it back on just past the marker.

Limited copies of the report are available from the Implementation Division.

A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks, Report No. FHWA–TS–81–210

by FHWA Implementation and Traffic Systems Divisions

This report describes a method for estimating motor vehicle fuel consumption and vehicle emissions in an urban driving environment. The method requires minimum field data collection and processing. The average transient speed as measured by travel time is a good composite parameter and is closely correlated with fuel consumption and vehicle emission rates.

Tables and figures are provided for fuel-speed and emission-speed profiles for a typical mix of passenger cars, single unit trucks, tractor-trailers, and buses.

The report provides a relatively easy and straightforward approach to gain insight into existing traffic operations and the merits of proposed or actual flow improvements.

Limited copies of the report are available from the Traffic Systems Division, HRS–31, Federal Highway Administration, Washington, D.C. 20590.

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New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. Space limitation precludes publishing a complete list. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R)—Performing State Highway or Transportation Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operatio for Safety

FCP Project 1I: Traffic Lane Delineation Systems for Adequate Visibility and Durability

Title: Develop a Low-Cost Raised Marker From Epoflex. (FCP No. 31I3053)
Objective: Develop and evaluate a low-cost reflectorized raised pavement marker for temporary situations using Epoflex pavement marking material.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78284
Expected Completion Date: November 1982
Estimated Cost: $69,000 (FHWA Administrative Contract)

FCP Project 1J: Improved Geometric Design

Title: Shoulder Geometrics and Use Guidelines. (FCP No. 51J2262)
Objective: Establish practical shoulder design and use guidelines from evaluations of existing shoulder designs and research.
Performing Organization: Hugh Downs, Baltimore, Md. 21202
Expected Completion Date: March 1983
Estimated Cost: $100,000 (NCHRP)

FCP Project 1M: Rural Highway Operational Safety Improvements

Title: Driver Needs on Two-Lane Rural Highways. (FCP No. 31M2062)
Objective: Review existing human factor literature to identify human factor limitations. Develop field methods for detecting driver information deficiencies as a function of traffic operational groupings.
Performing Organization: Institute for Research, State College, Pa. 16801
Expected Completion Date: September 1983
Estimated Cost: $590,000 (FHWA Administrative Contract)

FCP Project 1P: Visual Guidance for Night Driving

Title: Safety Considerations in the Use of Commercial Electronic Variable Message Signage. (FCP No. 21P2054)
Objective: Determine the impact of these signs on traffic and operator performance for a representative set of sign types and roadway and traffic conditions. Estimate the safety implications for different types of the signs.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: September 1982
Estimated Cost: $125,000 (FHWA Staff Research)

FCP Project 1V: Roadside Safety Hardware for Nonfreeway Facilities

Title: Breakaway Tunnel Terminal for Single Thrie Beam Barrier. (FCP No. 41V3312)
Objective: Impact test a breakaway terminal that can be attached directly to the end of the single thrie beam barrier.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95805
Expected Completion Date: July 1983
Estimated Cost: $117,000 (HP&R)

FCP Project 1W: Measurement and Evaluation of Pavement Surface Characteristics

Title: Evaluate Friction Requirements for California State Highways In Terms of Highway Geometrics. (FCP No. 41W2134)
Objective: Compare the measured skid numbers for each of several kinds of highway geometry. Determine the variations in skid number between the different kinds of highway geometrics for a given wet pavement accident rate.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95805
Expected Completion Date: September 1984
Estimated Cost: $109,000 (HP&R)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4J: Coating Systems for Controlling Corrosion of Highway Structural Steel

Title: Removal of Lead-Based Bridge Paint. (FCP No. 54J1113)
Objective: Identify potential worker safety and environmental impact problems that result from various lead paint removal techniques. Recommend steps for developing new technologies for removing and recovering lead paints.
Performing Organization: Offshore Power Systems, Jacksonville, Fla. 32211
Expected Completion Date: December 1982
Estimated Cost: $75,000 (NCHRP)

Title: Coating for Nonblast Cleaned Highway Metals. (FCP No. 34J3103)
Objective: Evaluate coatings for nonblast cleaned metal surfaces. Review existing technology to identify underprotected surfaces and appropriate coatings.
Performing Organization: Management Technology, Newton, Mass. 02159
Expected Completion Date: May 1984
Estimated Cost: $180,000 (FHWA Administrative Contract)

FCP Project 4K: Cost Effective Rigid Concrete Construction and Rehabilitation in Adverse Environments

Title: Evaluation of Experimental Installation of Silane Treatment on Bridges. (FCP No. 44K3184)
Objective: Test and evaluate experimental field installations of silane treatment on bridges in various sections of the State.
Performing Organization: Louisiana Department of Transportation and Development, Baton Rouge, La. 70804
Expected Completion Date: September 1986
Estimated Cost: $85,000 (HP&R)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5H: Protection of the Highway System From Hazards Attributed to Flooding

Title: Design of Rock Riprap for Protection of Encroachments. (FCP No. 35H1000)
Objective: Evaluate present riprap practice. Collect field data on flow in bends. Improve design procedures.
Performing Organization: U.S. Geological Survey, Sacramento, Calif. 95805
Expected Completion Date: September 1982
Estimated Cost: $300,000 (FHWA Administrative Contract)

FCP Project 5K: New Bridge Design Concepts

Title: Application of Adhesives to Bridge Structures. (FCP No. 35K1142)
Objective: Test spliced beams that have been reinforced with a structural adhesive to determine the effect of glue on increasing static strength and extending fatigue life.
Performing Organization: Blunt and Evans, Washington, D.C. 20005
Expected Completion Date: September 1983
Estimated Cost: $143,000 (FHWA Administrative Contract)

Title: Application of Transverse Prestressing to Bridge Decks. (FCP No. 45K3102)
Objective: Determine proper design criteria for transverse prestressing of bridge decks. Explore methods of providing corrosion protection for transverse prestressed tendons.
Performing Organization: University of Texas, Austin, Tex. 78746
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1984
Estimated Cost: $175,000 (HP&R)

Title: Rapid Bridge Deck Replacement. (FCP No. 45K3112)
Objective: Evaluate the effectiveness of several structural details and construction procedures for use of precast concrete members for rapid bridge deck replacement.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1984
Estimated Cost: $150,000 (HP&R)

FCP Category 6—Improved Technology for Highway Construction

FCP Project 6D: Pavement Rehabilitation

Title: Evaluate Effectiveness of Portland Cement Concrete Pavement Rehabilitation Techniques. (FCP No. 46D2844)
Objective: Determine relative effectiveness of the various rehabilitation techniques. Optimize particular techniques that will provide the most effective combined strategy rehabilitation for various pavement conditions.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95805
Expected Completion Date: September 1983
Estimated Cost: $100,000 (HP&R)

☆U.S. Government Printing Office: 1982—341–783/102

FCP Project 6E: Rigid Pavement Design and Construction

Title: Shoulder Rehabilitation Evaluation (Route I–78) to Identify a Cost Effective Means to Upgrade. (FCP No. 46E1534)
Objective: Evaluate several different methods of shoulder resurfacing, restoration, and rehabilitation.
Performing Organization: New Jersey Department of Transportation, Trenton, N.J. 08628
Expected Completion Date: June 1986
Estimated Cost: $24,904 (HP&R)

FCP Category 0—Other New Studies

Title: The Characteristics of Concrete on the Load-Carrying Capacity of Drilled Shafts. (FCP No. 40M1842)
Objective: Investigate the effects of slump on the load-carrying capacity of drilled shafts.
Performing Organization: University of Texas, Austin, Tex. 78763
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1983
Estimated Cost: $60,000 (HP&R)

Title: Permafrost Research Site Monitoring. (FCP No. 40M1852)
Objective: Evaluate various experimental features constructed to mitigate thermal changes and roadway movements in areas of discontinuous permafrost.
Performing Organization: Alaska Department of Transportation and Public Facilities, Juneau, Alaska 99801
Expected Completion Date: June 1983
Estimated Cost: $53,000 (HP&R)

Title: Reactive Silane-Coupled Asphalt/Mineral Composites as Binders in Paving Construction. (FCP No. 40M3712)
Objective: Investigate silane-coupling agent behavior relevant to mineral fillers and asphalt. Develop procedures of making composites and using them as binders.
Performing Organization: Arizona Department of Transportation, Phoenix, Ariz. 85007
Expected Completion Date: September 1983
Estimated Cost: $72,000 (HP&R)

Title: Fabric Forms With Cement-Flyash Mixture for Erosion and Sediment Control. (FCP No. 40M4143)
Objective: Determine the characteristics of cement-flyash mixture for erosion control structures and the feasibility of using nylon fabrics as placement forms instead of wood or metal forms.
Performing Organization: Research and Development, Oklahoma City, Okla. 73105
Funding Agency: Oklahoma Department of Transportation
Expected Completion Date: July 1985
Estimated Cost: $88,000 (HP&R)

Title: Evaluation of Rapid-Setting Repair Materials for Concrete Pavements and Bridges. (FCP No. 40M5674)
Objective: Select and evaluate the most promising rapid-curing repair materials for portland cement concrete pavements and bridges. Test in the laboratory to determine mechanical properties and cure times at different temperatures. Test in the field to determine optimum mixing, placement, finishing methods, and performance. Develop a users manual.
Performing Organization: University of Texas, Austin, Tex. 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1984
Estimated Cost: $250,000 (HP&R)

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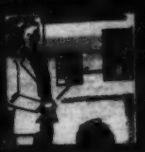

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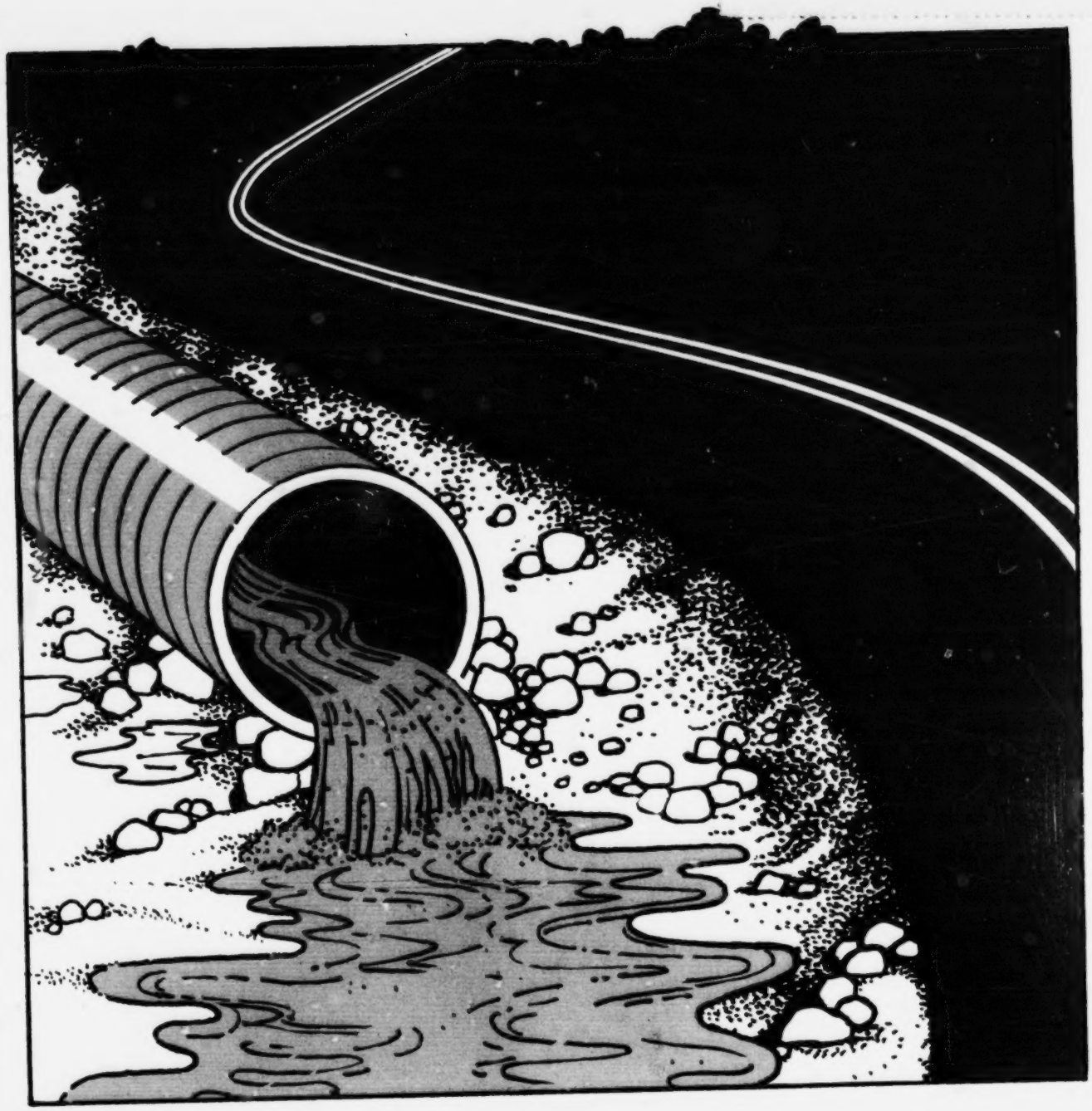

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COVER:
Scour at culvert outlets is a concern of highway engineers today.

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Scour at Culvert Outlets in a Sandy-Clay Material

by

Steven R. Abt, J. Sterling Jones, and James F. Ruff

Introduction

One of the major considerations in the design and construction of a highway system is strategically placed culverts of various shapes and materials to insure tributary drainage through the roadway embankment. As flow passes through the culvert and out of the culvert barrel, the resulting water jet impinges upon the material beneath the culvert outlet. The discharging water entrains and transports material particles downstream of the culvert outlet. The result of this scour process is the degradation of the roadway embankment, degradation of the area beneath and adjacent to the culvert outlet, and aggradation of the channel, land areas, or properties downstream of the outlet.

The Federal Highway Administration (FHWA) sponsored a research study in cooperation with Colorado State University to investigate the scour process at culvert outlets. Costly energy dissipators frequently are installed when *estimated* culvert outlet scour is high, and the study developed better methods to predict when dissipators are needed. Currently used procedures for estimating culvert outlet scour are based primarily on tests using a fine sand. (*1*)[1] The FHWA study was initiated to determine adjustment factors for materials that have more resistance to scour and was designed to augment a related study. (*2*) Because most material found adjacent to culvert locations are cohesive, a cohesive sandy-clay material was included in the experimental plan.

However, because so many parameters could affect scour in cohesive materials, there was no assurance that general conclusions could be drawn from tests on a single cohesive material. Nevertheless, the study did show that the inverted shear number, a parameter that can be determined from standard soils tests, has the potential for correlating scour depths not only in cohesive soils but in noncohesive soils as well. That potential, although it may require further development and verification, is encouraging because it means the scour process for cohesive soils can be defined reasonably well with a limited number of experiments. Otherwise, an extensive research program would be required to define the expected scour process in cohesive soils.

[1] Italic numbers in parentheses identify references on page 5.

Testing Program

A hydraulic model study was performed at the Colorado State University research facilities to simulate field conditions of a newly placed culvert. An outdoor flume 30.5 m (100 ft) long, 6.1 m (20 ft) wide, and 2.4 m (8 ft) deep was constructed (fig. 1). The culvert outlet was centered between the flume sidewalls with the culvert invert adjacent to the bed material. Circular culverts with 254 mm (10 in), 356 mm (14 in), and 457 mm (18 in) diameters were tested in the cohesive bed.

The cohesive bed material used in the experiments was a Colorado sandy-clay with a sandy loam texture. The material was dumped into the facility, spread to a uniform depth of approximately 152 mm (6 in), and rolled with a specially designed and constructed roller (fig. 2) to insure a uniform density of 90 percent of the optimum density throughout the test bed. The material was layered in 152 mm (6 in) lifts to a depth of 1.8 m (6 ft) where the bed became adjacent to the culvert invert.

Discharges through the three culverts ranged from approximately 0.057 to 0.850 m^3 per second (2 to 30 ft^3 per second). Each test with the cohesive material was run for 1,000 minutes with data collected at intermediate times. During and after testing, each scour hole was contoured, and the influence of aggradation downstream of the scour hole was recorded (fig. 3).

Results

A series of scour hole dimensions for various flow and soil conditions was developed from the experiments. General observations recorded during the cohesive soil testing include the following:

- When the culvert flowed full, the scour holes were oval shaped. When the culvert did not flow full, scour holes tended to be circular.
- A small mound developed downstream of each scour hole. The mound extended several scour hole lengths downstream of the culvert outlet.
- The bottom of the scour hole, areas adjacent to the scour hole rim, and the mound downstream of the scour hole became armored.
- In some cases, vertical walls were observed in the scour hole. As the hole drained and dried, the walls collapsed into the bottom of the hole.
- As the pipe size and/or the discharge increased, the scour hole dimensions increased.

Traditionally, scour data have been depicted with scour hole dimensions—depth, length, width, and volume—as functions of the discharge intensity, which is a ratio of culvert discharge to the culvert diameter. Model to prototype similitude was verified by comparing test results from various culvert models. Acceptable similitude occurs when dimensionless scour hole characteristics are related to the dimensionless discharge intensity parameter as illustrated in figure 4. In other words, although this figure was developed from a small diameter model, it may be used to predict scour at the outlets of large diameter field culverts with the same soil type.

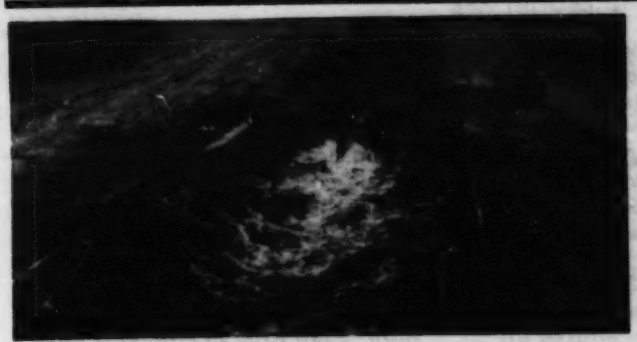
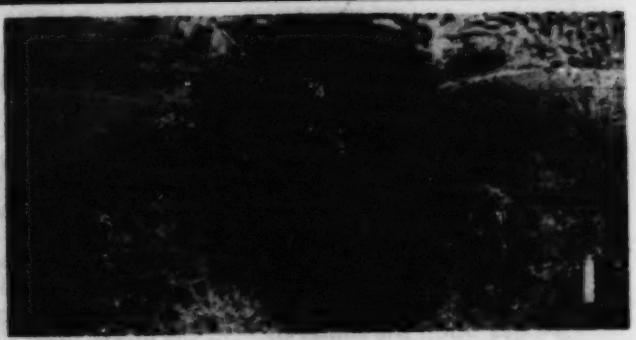


Figure 1.—Outdoor testing facility.



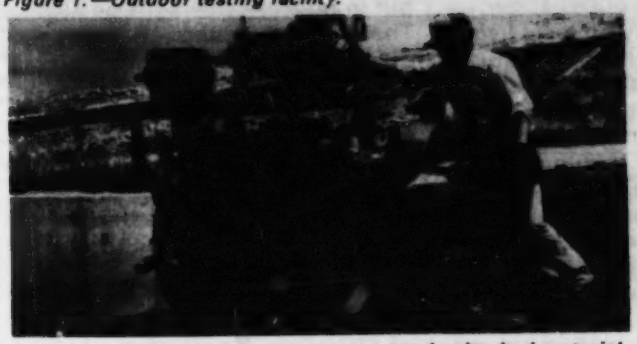


Figure 2.—Roller used to compact the sandy-clay bed material.

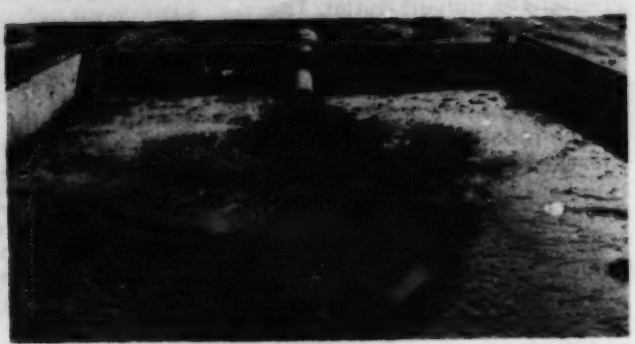


Figure 3.—Scour hole after 1,000 minutes of testing in a 254 mm (10 in) diameter pipe (top), and aggradation downstream of the scour hole (bottom).

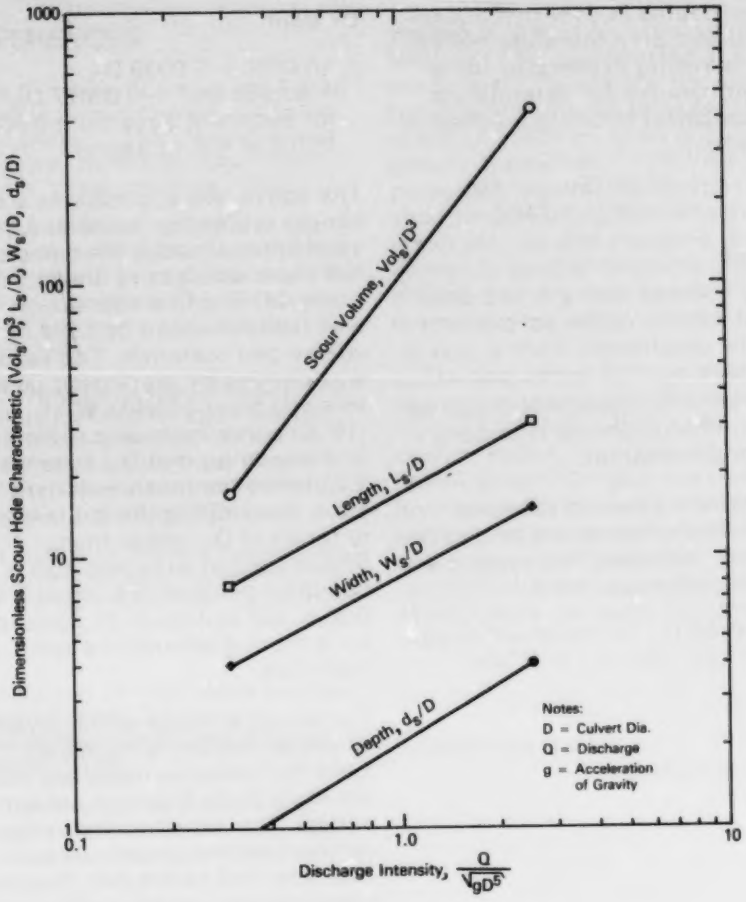
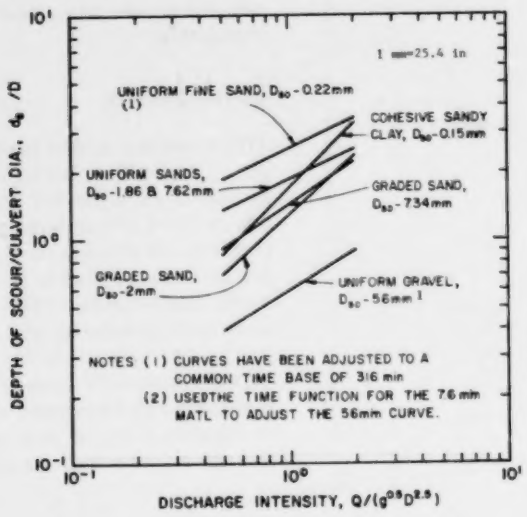


Figure 4.—Scour hole characteristics versus discharge intensity for a cohesive sandy-clay (time =5 hours).


DEPTH OF SCOUR/CULVERT DIA., d_s/D
10^1
10^0
10^{-1}
10^{-1}
10^0
10^1
1 mm=25.4 in
UNIFORM FINE SAND, D_{50} - 0.22mm (1)
COHESIVE SANDY CLAY, D_{50}-0.15mm
UNIFORM SANDS, D_{50} -1.86 & 762mm
GRADED SAND, D_{50} - 734mm
GRADED SAND, D_{50}-2mm
UNIFORM GRAVEL, D_{50} - 56mm [1]
NOTES (1) CURVES HAVE BEEN ADJUSTED TO A COMMON TIME BASE OF 316 min
(2) USEDTHE TIME FUNCTION FOR THE 76 mm MATL TO ADJUST THE 56mm CURVE.
DISCHARGE INTENSITY, $Q/(g^{0.5}D^{2.5})$

[1] Data for the 56 mm uniform gravel are from T. R. Opie, "Scour at Culvert Outlets," M.S. thesis, Colorado State University, Fort Collins, Colo., December 1967.

Figure 5.—Cohesive and cohesionless material, d_s/D versus D.I. curves adjusted to a common time base of 316 minutes.

To compare the effects of various soil types, figure 5 shows the dimensionless scour *depth* versus discharge intensity for most of the soil types that have been tested either in prior research or in this study. Other scour hole dimensions—length, width, volume—would have a similar pattern for various soil types.

Figure 5 also illustrates the traditional means for estimating scour at culvert outlets. The top curve of figure 5 is the basis of an FHWA procedure. (*3*) Some State highway agencies have applied constant adjustment factors to the values in the FHWA procedure for various soil types, but those adjustment factors have little experimental basis. Although figure 5 is adequate to estimate culvert scour in noncohesive bed materials by interpolating between curves, it is not adequate for cohesive soils. An extensive testing program would be necessary to bracket the various cohesive soils. Lacking the resources for such a program, a more expedient procedure was developed using data for noncohesive soils to supplement very limited data for cohesive soils.

In analyzing the data for the cohesive soil, the investigators at Colorado State University found good correlation between scour hole dimensions and an inverted shear number. The inverted shear number is defined as follows:

$$ISN = \rho V^2/\tau_c$$

Where,

ρ = Mass density of water.
V = Average culvert outlet velocity.
τ_c = Critical shear stress.

The numerator of the inverted shear number is proportional to (but not equal to) the shear stress, which tends to erode the soil; the denominator is the level of stress at which the soil can resist erosion. Intuitively, this combination of terms should correlate well with scour.

Empirical relationships were derived for scour dimensions as functions of the inverted shear

number for the one cohesive soil that was tested. The applicability of these relationships to soils other than a sandy-clay material then was tested.

If the shear number relationships are to be generally applicable, they should work as well for noncohesive as for cohesive materials. Although only one cohesive material has been tested, several noncohesive materials have been tested over the years. Figure 6 is a plot of points for both cohesive and noncohesive materials. Like figure 5, figure 6 illustrates the concepts rather than design curves. Figure 6 illustrates that the curves of figure 5 for various soils can potentially be reduced to a single line when the inverted shear number is used as the independent variable plotted along the abscissa.

Except for the critical shear stress, the variables in the inverted shear number are readily available. The critical shear stress is somewhat of a problem for cohesive materials, but there is a much better data base for the critical shear stress than there is for scour depths in cohesive materials. Based on a literature review, the following expression (*4*) is recommended for determining critical shear stress in a cohesive material:

$$\tau_c = 0.001\ (Sv_{sat} + 180) \tan (30 + 1.73PI)$$

Where,

Sv_{sat} = Shear strength of a saturated sample of the soil, which can be determined from a triaxial soil test.

PI=Plasticity index, which can be determined from the Atterburg limits soil test. (*5*)

The critical shear stress for a noncohesive material can be adequately estimated (for scour prediction purposes) from

$\tau_c = 0.0164\ D_{75}$ for sediment sizes larger than 0.2 in (5 mm)

Where,

τ_c is in pounds per square foot.
D_{75} is in inches.

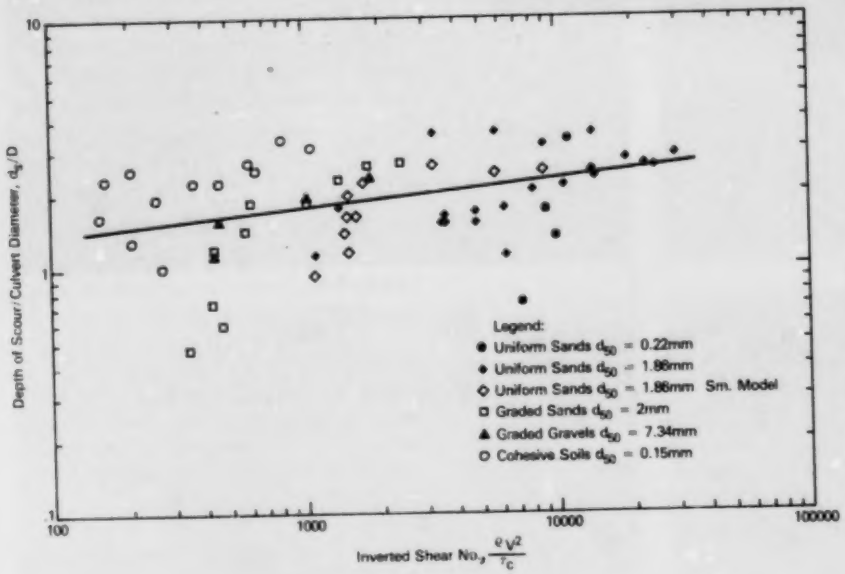
Or from

$\tau_c = 0.0024 + 0.0039\ D_{75} + 0.0033\ D_{75}^2 + 0.00027\ D_{75}^3$ for sediment sizes from 0.008 to 0.2 in (0.2 to 5 mm)

The above two expressions are simply regression equations that yield approximately the same critical shear stresses as Shield's diagram. (*6*) The first expression was recommended by Lane for coarse bed materials. The second was derived by regressing points selected from Shield's 60° F (16° C) curve for quartz sediment and assuming that D_{75} sizes were 1.25 times the mean sediment sizes. Developing the expression in terms of D_{75} rather than Shield's mean sediment size is desirable because the larger fraction of the soil tends to account for armoring effects of graded materials.

The practical range of the inverted shear number is from 5 to 5,000 for cohesive materials that are likely to be found at culvert outlets. The experimental range for the inverted shear number was from 150 to 220,000, but the higher values were for noncohesive materials. The range for cohesive materials was from 150 to 1,000. The line through the data in figure 6 is a reasonable basis for estimating scour for the expected range of cohesive materials.

Figure 6.—Scour depth versus inverted shear number (time=5 hours).



Conclusions

The inverted shear number appears to be a good primary independent variable for estimating scour hole dimensions based on the limited experimental culvert scour data available for cohesive soils. Superimposing noncohesive with cohesive soil data was useful for extrapolating the limited cohesive soil data. FHWA will evaluate the concepts illustrated in figures 5 and 6 and will update design curves and equations. (*3*)

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James F. Ruff is in charge of civil engineering projects for a firm in Laramie, Wyo. Previously, he was an associate professor of civil engineering at Colorado State University and was the original principal investigator for the FHWA research study. Dr. Ruff currently is involved in energy development, water resource, and water supply projects in Wyoming.

Reduction of Truck-Induced Splash and Spray

by
George B. Pilkington, II

Introduction

A truck traveling on a roadway can adversely affect the safety of adjacent motorists in smaller vehicles by causing aerodynamic disturbance and, on wet pavements, splash and spray. Aerodynamic disturbance, pressure or suction forces induced by a truck on an adjacent vehicle, can alter the adjacent vehicle's path. Splash results when the impact of a tire on the pavement forces water out of the tire-pavement interface. Generally, these water drops follow a ballistic path away from the tire and are larger than 1 mm (0.04 in) in diameter. Spray is formed when water droplets, generally less than 0.5 mm (0.02 in) in diameter and suspended in the air, atomize upon impact with a smooth surface.

Previous research shows that aerodynamic disturbance is the most hazardous of the three effects. (*1*)[1] However, because splash and spray are visible, they are perceived as more hazardous.

Many factors must be considered in studying the effects of splash and spray. Splash and spray occur only when the following five elements combine:

- Water in the tire path.
- Pavement surface water retention. Water generally is retained on a nonporous pavement, such as portland cement concrete or dense-graded asphaltic concrete, or in depressions in rutted or rough pavements.
- High velocity air in a turbulent flow pattern.
- High velocity air induced by truck speed.
- Turbulent air flow patterns around the wheels and through gaps caused by truck configuration.

Previous Research

Research completed in 1972 for the Federal Highway Administration (FHWA) analyzed and evaluated the effect of truck-induced aerodynamic disturbances on the control and handling of passenger vehicles. The following were found:

[1] Italic numbers in parentheses identify references on page 12.

• The aerodynamic disturbance induced by trucks has a measurable adverse effect on the control and handling of an adjacent passenger car. The magnitude of this effect increases with an increase in the vehicles' speed or size and decreases as the lateral separation of the two vehicles increases. The maximum aerodynamic disturbance effect occurs when the relative speed of the two vehicles is between 5 and 35 km/h (3 and 22 mph) and the passenger vehicle is downwind, traveling in the same direction as the truck. For example, on a two-lane highway having a lane width of 3 m (10 ft), the passenger vehicle could be drawn toward the truck or blown toward the shoulder depending on the ambient wind direction. (*1*)

• The critical areas of induced aerodynamic effect for a truck combination are the front of the tractor (bow), the gap between the cab and trailer and around the driving wheels, the rear semitrailer wheels, and the rear of the combination (tail) (fig. 1). If there are additional trailers in the truck combination, the additional gaps between trailers and around front trailer wheels also become critical areas. (*1*)

• A truck combination near a passenger vehicle causes stress in the vehicle driver. (*1*)

Based on early research on the formation of splash and spray (*2*), the National Highway Traffic Safety Administration (NHTSA) sponsored research to develop a technique to contain splash and spray generated by truck wheels. This research resulted in a prototype fender (the Department of Transportation Spray Protector [DOT fender]) that effectively contained splash and spray. (*3*) However, the DOT fender never was implemented because subsequent operational tests showed that it reduced the air circulation around the wheels causing the brakes to overheat and fade. (*4*) The NHTSA field tests demonstrated that techniques to reduce splash and spray should be evaluated operationally to insure that solving one problem does not cause a new problem. (*1*)

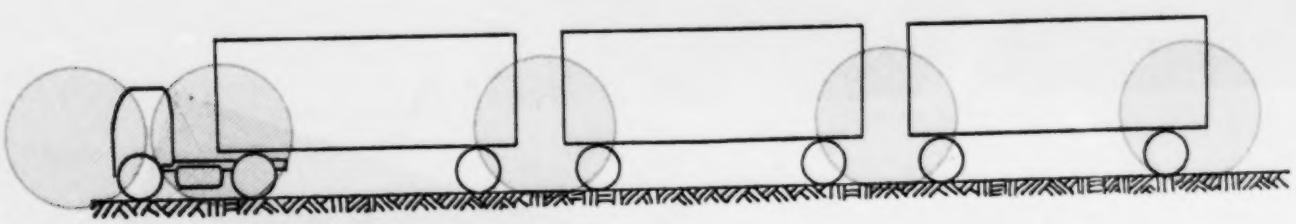
Full-scale testing techniques used in England and Sweden to measure spray volume and density were combined with the basic full-scale test setup used in the NHTSA field tests to develop the setup for subsequent full-scale splash and spray research. (*4–6*)

Research for the Transportation Systems Center (*7*) and the National Science Foundation (*8*) developed several efficient methods to reduce aerodynamic drag. It was determined that the efficiency of a splash and spray reduction technique could be enhanced when used with a drag reduction device.

Splash and Spray Research

A major FHWA study on splash and spray was conducted under Project 1U, "Safety Aspects of Size and Weight of Heavy Vehicles," in the Federally Coordinated Program of Highway Research and Development. (*9*) The research study included wind tunnel experiments, driver simulator experiments, full-scale tests with various truck configurations and truck-mounted devices to improve air flow around the trucks and reduce splash and spray, cost effectiveness analyses, and over-the-road evaluations in coordination with manufacturers.

Figure 1.—Critical areas of vehicle-induced aerodynamic disturbance.



Wind tunnel experiments

Two series of wind tunnel experiments using one-tenth scale models were conducted. The first series of experiments determined the magnitude and direction of the air flow patterns around a single combination truck. Figure 2a shows the experimental setup for the single truck experiments. The "tufted" model and "tufted" rake[2] are mounted on the wind tunnel yaw table. This photograph, taken during an experiment, shows the free end of the tufts alined with the direction of the air flow. Figure 2b graphically displays the data collected from the same experiment. It is apparent that the cab wake and the tandem wakes are the regions of highest turbulence. Also apparent is the longitudinal distortion of these turbulent regions along the direction of air flow.

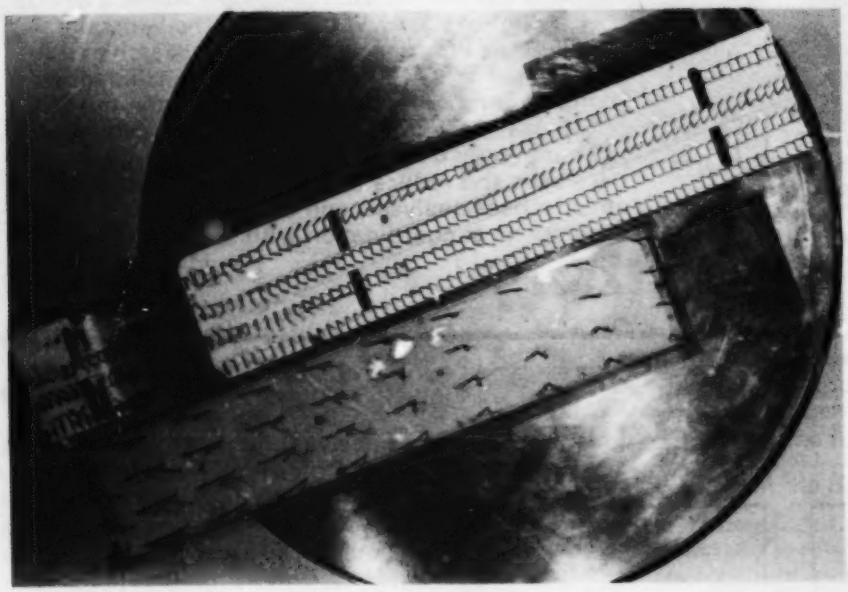
[2] A device having 40 pitot tubes to determine the air pressure at various locations.

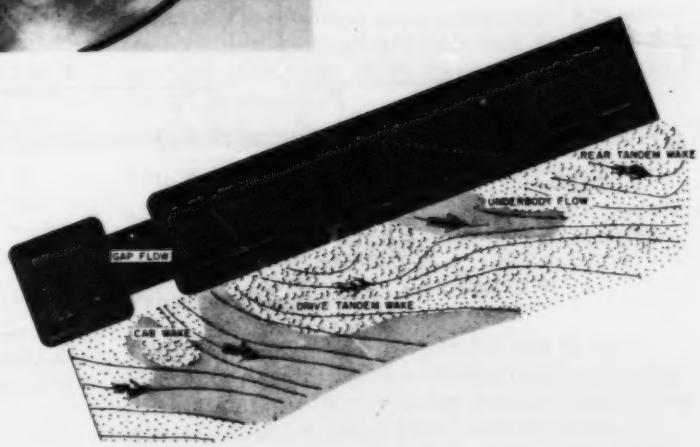
The second series of wind tunnel experiments determined the effect of the air flow pattern caused by a combination truck on an adjacent passenger vehicle. Figure 3a shows the two-vehicle wind tunnel experimental setup, and figure 3b illustrates the magnitude and direction of air pressure on the passenger vehicle caused by the truck.

Driver simulator experiments

Subjects in FHWA driver simulator experiments were shown simulated spray clouds that obscured vision to different degrees. It was found that temporarily losing view of the highway because of a spray cloud did not cause a passenger vehicle driver to lose control of the vehicle. The driver simulation lacked the realism of the presence of the truck, which increases driver stress, but this was not

Figure 2.—(a) Single combination truck wind tunnel test; typical tuft photograph. (b) Interpretation of single combination truck wind tunnel data.





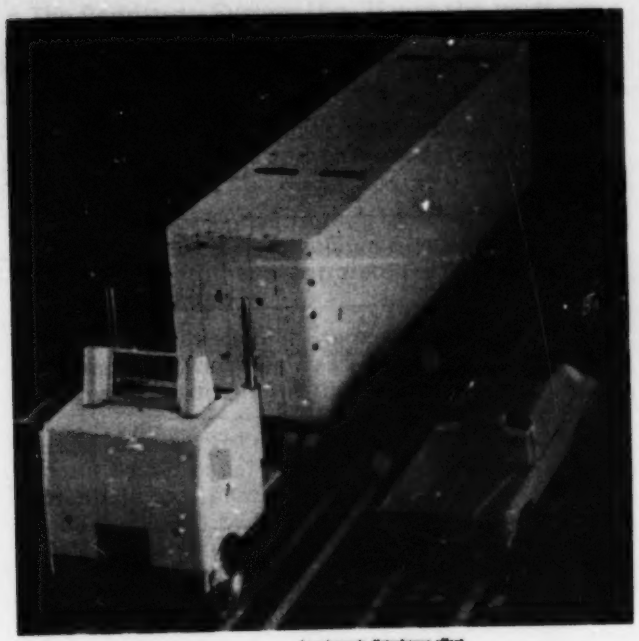


Figure 3.—(a) Two-vehicle wind tunnel test; basic truck with drag shield and station wagon. (b) Interpretation of two-vehicle wind tunnel data.

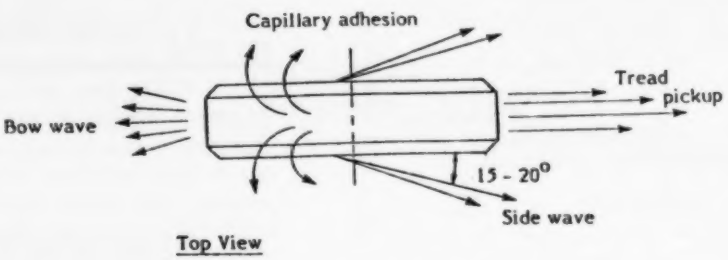
considered a detriment to the basic findings. Another purpose of the driver simulator experiments was to acquaint the drivers that would participate in the full-scale experiments with the visual loss they would experience when actually driving in a spray cloud near truck combinations.

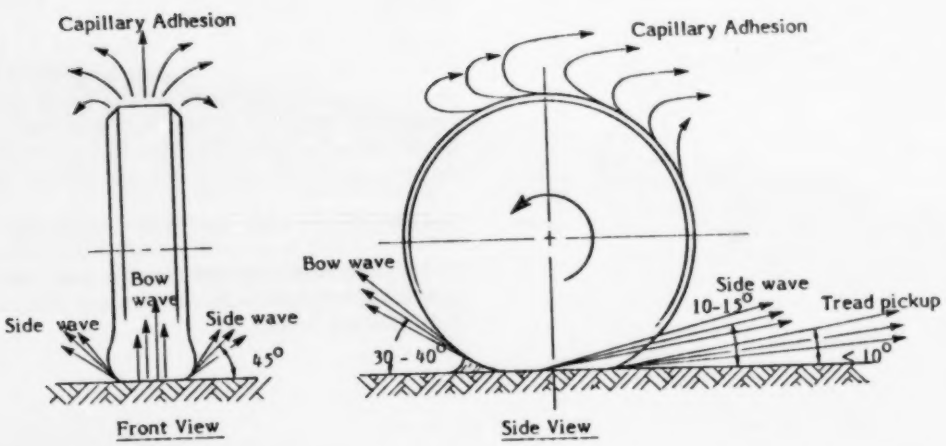
Full-scale experiments

Three series of full-scale experiments were conducted. The first series determined how splash and spray from a single or double wheel are formed. These experiments demonstrated that the cause of splash is primarily from the side throw of water away from the wheel, and the ballistic path of the splash is generally below the wheel. The primary source of spray is water from tread pickup being thrown from the tire because of high-speed wheel rotation and atomizing upon impact with a hard surface. The only direct source of spray is the water that remains on the tire from capillary adhesion and is stripped from the top of the tire by the air flow. Spray from this source, however, constitutes only 1 percent of the spray cloud. The sources of splash and spray are shown in figure 4.

The second and third series of full-scale experiments were conducted in a desert to determine the most critical truck combination to splash and spray generation and the most promising splash and spray reduction device. Additional objectives included determining the

Figure 4.—Splash and spray sources.



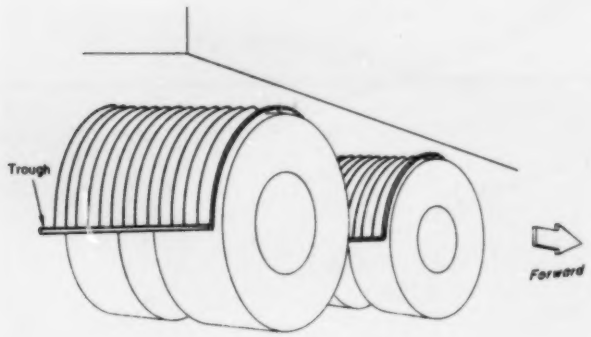


effect of truck weight on splash and spray generation, the characterization of spray, and subjective and objective assessments of splash and spray.

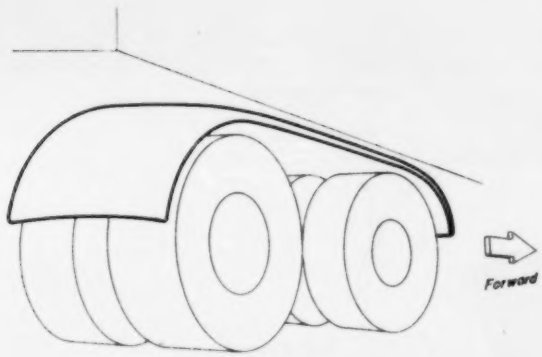
These experiments were conducted in the desert so that pertinent environmental conditions—wind and water—could be controlled. Previous aerodynamic disturbance research had shown that wind in the desert was relatively constant both in magnitude and direction. In these experiments, water was pumped to the site and evenly distributed on the 300 m (984 ft) test track pavement surface through holes in an irrigation pipe. The water depth was maintained at approximately 1.5 mm (0.06 in).

The truck combinations tested were cab-behind-engine (CBE) and cab-over-engine (COE) tractors with flat bed, tanker, and van semitrailers and trailers in single, double, and triple configurations. Off-the-shelf splash and spray reduction devices, such as those shown in figure 5, were evaluated as were prototype truck-mounted devices shown in figure 6.

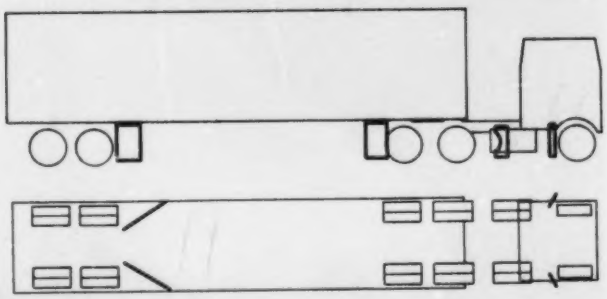
Figure 5.—Off-the-shelf splash and spray reduction devices.



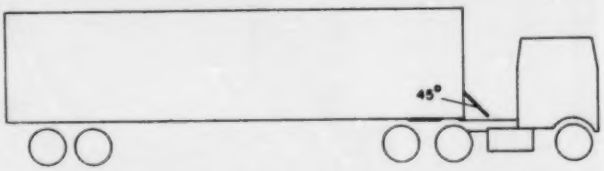
Roberts Fender



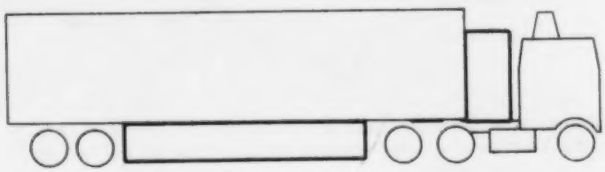
European Fender



Angled side vane



Partial gap panel concept



Underbody baffle and splitter panel

Figure 6.—Prototype truck-mounted devices to reduce splash and spray.

Loaded and empty van combinations were tested to determine the change in the quantity of splash and spray and pressure patterns caused by increased weight. The spray cloud was "fingerprinted" by capturing the water droplets on a screen for 1 minute to determine their size and frequency. The water volume of the spray cloud was collected at the same time. Spray-attenuation signals from a photometer and lasers parallel to the test track measured the spray cloud density. In addition, tractor cab passengers, passengers in adjacent vehicles, and observers at the ends of the test track rated the visibility of the highway and truck depending on their interpretation of the deterioration of safety caused by the spray cloud.

Data analyses indicated the following:

- The COE and van semitrailer was the most critical combination, causing the largest aerodynamic disturbance effect.

- The Reddaway System (fig. 7) was the most effective system in reducing splash and spray, though all devices and techniques showed promise with better product engineering.
- The weight of a truck combination had little effect on the splash, spray, and air flow patterns generated.
- Additional subjective ratings of visibility were unnecessary because objective measures using the lasers and photometer correlated well with the subjective ratings.
- The change in visibility caused by the various truck-mounted devices was a reliable indication of changes in aerodynamic disturbances and spray.

Using the results of the first desert experiments, the second desert experiments concentrated on obtaining more precise data on the change in visibility caused by various promising devices. Twenty-seven truck configurations were evaluated, and four "paired" test runs were made of the basic truck with each truck with a splash and spray reduction device. The modified truck traveled through the test area and appropriate measures were obtained. The basic truck traveled through the test area approximately 1 minute later—after the water film and environmental conditions had returned to pretest conditions. Of the 27 splash and spray reduction devices evaluated, visibility improved as much as 60 percent in some and decreased as much as 18 percent in others compared with a truck without a drag shield or reduction devices. The most effective reduction device combination was the Reddaway System and a drag shield. The Reddaway System without a drag shield was only two-thirds as effective in reducing splash and spray; the drag shield without the Reddaway System improved visibility only 5 percent. Table 1 gives the percent changes in visibility for each splash and spray reduction device tested. (*9*)

Cost effectiveness analyses

Cost effectiveness analyses indicated that the Reddaway System with drag shield and longitudinal baffle was the most cost effective of all devices tested. Its benefit-cost ratio was about 16:1. (*9*) The economic analysis considered the higher capital cost of the Reddaway System (approximately $800), the higher cost of maintaining the system (approximately $200 per year), and a 0.6 percent decrease in the revenue load (approximately 160 kg [352 lb]). These "losses" are offset by an approximately 2.7 percent savings in fuel because of reduced drag and cross flow. The overall net savings was approximately 1.25 cents per kilometre (2 cents per mile), or an annual savings of $400 per truck. (*9*)

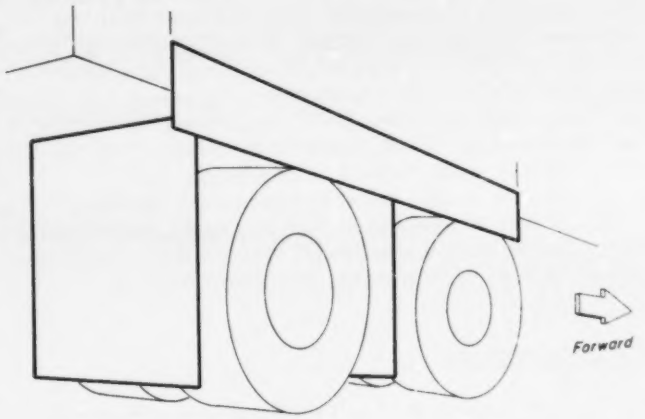


Figure 7.—Sketch of Reddaway Fender.

Table 1.—Visibility changes caused by splash and spray reduction devices

Devices	Description	Visibility changes
		Percent
M0	Reddaway System and drag shield	60
M6	Like M2, drag shield and longitudinal baffle	59
M7	Like M2 and drag shield	59
M2	Like M1, without flaps between the tandems	39
M1	Reddaway System	38
M3	Like M1, without front flaps	25
L1	Longitudinal baffle, gap splitter panel and drag shield	25
G1	Gap filler panel in upper position	23
V3	Like V2, without vanes behind tractor tandem	20
L2	Longitudinal baffle and gap splitter panel	20
R1, R2	Roberts Fender with and without drag shield	19
F3	Fuzzy truck drag shield and longitudinal baffle	17
V2	Angled side vanes and drag shield	16
M4	Like M2 without side flaps	15
L4	Longitudinal baffle and drag shield	15
V4	Angled side vanes and drag shield, reset	15
E2	European fender	15
F2	Fuzzy truck and drag shield	14
M5	Like M4, without rear flaps on tractor	14
G2	Gap filler panel in lower position	11
L3	Longitudinal baffle	10
P3	Partial gap panel and angled end plates	7
D1	Basic truck and drag shield	5
T	Basic truck	0
P2	Partial gap panel and straight end plates	-1
P1	Partial gap panel	-11
F1	Fuzzy truck	-12
V1	Angled side vanes	-18

Research Results and Benefits

This research successfully demonstrated that the adverse aerodynamic effects of large trucks can be reduced by devices that effectively reduce splash and spray. With the cooperation of several commercial truck lines, NHTSA currently is supplementing FHWA research by developing life-cycle costs—manufacture, installation, and maintenance costs—of spray reduction devices. NHTSA also is developing simpler test procedures than those used in the desert tests to determine the effectiveness of new spray reduction devices.

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[3]Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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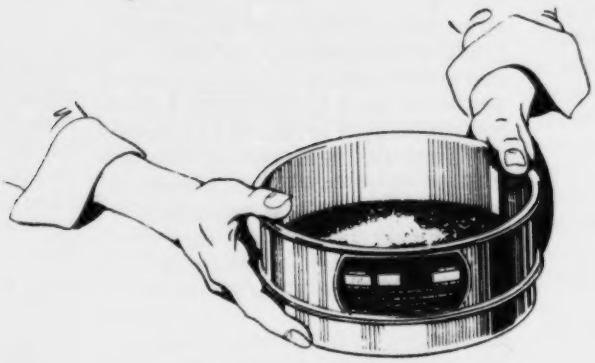
Aggregate Gradation Control: Part I—An Analysis of Current Aggregate Gradation Control Programs

by
Peter A. Kopac, Jose I. Fernandez, Stephen W. Forster, and Terry M. Mitchell



Introduction

The gradation test, probably the most frequently performed test in highway construction, is performed by all parties closely involved in actual construction work. The test is performed by technicians representing State highway agencies, contractors, aggregate producers, and materials suppliers that include bituminous concrete (BC) plants, portland cement concrete (PCC) plants, and concrete block plants. The test is performed when aggregate is manufactured, before and after aggregate is incorporated in the concrete mixture, at the job site, and at various testing laboratories. Furthermore, it is performed for both process control (controlling the product quality) and acceptance (determining product quality).

Although many State highway agencies recently have reduced their day-to-day process control activities, State personnel still perform a large, possibly disproportionate, amount of aggregate gradation process control testing. A recent research study sponsored by the Federal Highway Administration (FHWA) indicates that the total cost of aggregate gradation control—the overall combined testing-related costs for all parties involved—can be minimized by shifting the responsibility for most of the sampling and testing from the States to the contractors. (*1*)[1] The study reveals that States that perform their own aggregate gradation process control may be expending as much as 18 times the effort as States that have adopted more modern quality assurance-quality control (QA–QC) gradation programs. Wages for State inspectors performing gradation testing are $2 million or more per year in many States, so the potential for savings is considerable.

Should more States, then, shift to gradation process control by the contractor? What exactly are "QA–QC" programs? How do they work? Do they offer advantages to contractors, materials suppliers, and producers or only to State highway agencies? And what happens to product quality when the State transfers process control responsibilities? These questions, as well as others, were investigated in FHWA's research and will be addressed in this two-part article. Part I presents a comparative analysis of current gradation control programs to

[1] Italic numbers in parentheses identify references on page 24.

determine direct and indirect economic benefits and liabilities. Part II, to be published in the next issue of *Public Roads*, will provide guidelines for implementing an efficient gradation control program that can be used directly by highway agencies and that defines effective producer-contractor-highway agency functions and responsibilities.

Process Control of Aggregate Gradation

Process control is the maintenance or control of a certain characteristic or set of characteristics for a product during its manufacture or processing. In aggregate processing, one of the characteristics controlled is the gradation of the particles. The gradation testing is carried out because it is felt that uniformity in gradation is necessary to obtain the required quality in those materials or structures in which the aggregate is used. What is being tested, however, is the aggregate and not the quality of the final product.

Because State highway agencies usually do not produce aggregate, any use of aggregate by the State will involve at least two of the following parties: the producer who processes the aggregate, the trucker who transports the aggregate, the concrete (either PCC or BC) supplier who uses the aggregate as an ingredient of the product, the contractor who incorporates that product into the actual highway facility, and the State highway agency as purchaser and consumer.

State highway agencies traditionally have assumed the responsibility for the tests and inspections necessary to assure conformance with the aggregate specifications. Occasionally, this has created serious problems. Legally, the responsibility for providing materials and products of the specified quality rests with the construction contractor. Whenever a State gets involved in the contractor's quality control activities, the State assumes an implicit liability for the quality of the product. In recognizing this, many States have imposed specific gradation control testing requirements upon the producer and the contractor. However, until better methods are developed to evaluate the quality of the finished product, there must be a mechanism to determine the acceptability of the aggregate. Therefore, some amount of aggregate gradation testing usually is performed by the State, even in those States in which the primary responsibility for aggregate gradation control testing lies with the producer or the construction contractor.

Sampling for aggregate gradation testing may be performed at the aggregate source, the concrete plant, or the project site from conveyor belts, stockpiles, storage bins, trucks, or directly from the roadway. The point of sampling should be chosen so that the aggregate sampled is most representative of the aggregate in the final product. At the same time, impractical sampling requirements should be avoided.

The time and frequency of sampling and testing usually are related to working hours and production quantities. Again, practicality is important because the frequency of sampling directly impacts the overall costs of an aggregate gradation testing program.

Standard methods for gradation testing of aggregate should be followed to minimize problems in the event of a possible liability claim. These standard methods are prescribed by associations (*2, 3*) or individual State highway agency manuals; in many cases, rapid and simplified methods are available and may be followed.

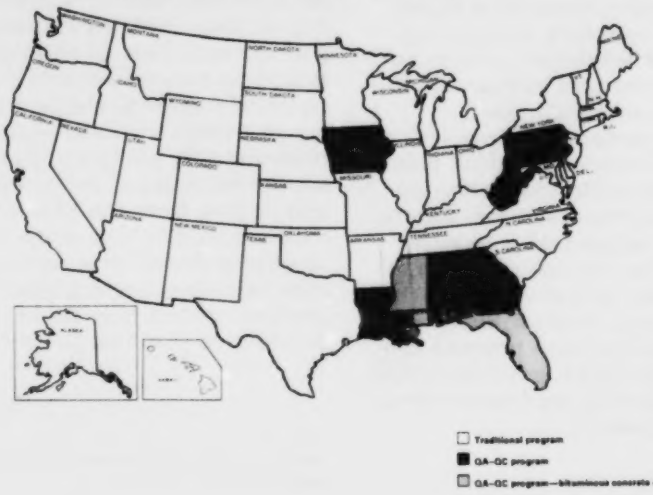
Current Gradation Process Control Programs

Aggregate gradation control programs can be divided into two broad groups based on who is responsible for performing the majority of aggregate gradation tests.

In "traditional" programs, the State highway agency has the traditional role of performing the majority of aggregate gradation control and acceptance tests. Producers and concrete suppliers may have an internal aggregate gradation control program for their own benefit; however, their tests seldom are used by the State.

In QA–QC programs, the State highway agency performs the testing for verification and/or acceptance (quality assurance), while the contractor, concrete supplier, and/or the producer performs the majority of aggregate gradation testing for process control (quality control). Currently, only a few States use this kind of program (fig. 1), and for most of

Figure 1.—Kinds of gradation control programs (1978).



these States, the program is relatively new. Most States using this program still retain responsibility for acceptance testing. Some require that control testing be performed at the aggregate source; others primarily are concerned with testing in the concrete plant. In some States, a pilot QA–QC program has been established for specific areas of the State; in still other States, a combination program using both traditional and QA–QC features is being used, depending on the application of the aggregate.

The concept of statistical variability can be incorporated in either kind of program by including statistical tolerances on the aggregate gradation specifications, statistically evaluating test results, statistically analyzing the correlation between control tests and verification tests, or any combination of the above.

Program descriptions

Gradation control programs in three States were investigated in detail. State A represents a QA–QC program with emphasis on testing at the aggregate source, State B represents a QA–QC program with emphasis on testing near the point of use, and State C represents a traditional program.

To more easily compare different gradation control programs, three entities within each State highway agency—the central laboratory, the district laboratories, and the offices of the Resident Engineers—must be defined. The central laboratory is the principal laboratory facility maintained by the Materials Section. The district laboratories (sometimes called the regional laboratories) are laboratory facilities maintained by the Materials Section at locations that conveniently service a specifically designated geographical area. At the project level, the office of the Resident Engineer represents the primary point of contact and interaction between the State and the construction contractor during the execution of the project. The Resident Engineers usually are under the jurisdiction of the Construction Section of the State agency, not the Materials Section.

State A program

The aggregate gradation control program of State A is a QA–QC program with the aggregate producer responsible for the quality control testing of aggregates. Each shipment of aggregate to a project site or concrete plant must be accompanied by a certificate of compliance. Producers are required to employ State-certified technicians at each source to perform process control gradation testing. One gradation test is required for each 1.4 Gg (1,500 tons) of each class of aggregate produced.

The State agency has 21 Resident Engineers. The office of the Resident Engineer is responsible for acceptance of aggregates and products at the project level, including all sampling and any necessary testing of base and subbase materials and PCC aggregates. Aggregate used for base or subbase material requires only visual inspection, but testing also may be conducted if the material appears to be marginal. At the PCC plant, three samples of aggregate are taken for each 191 m^3 (250 yd^3) of concrete produced, with a minimum of three samples per each day's production. Usually, only one of these samples is tested; the other two are tested only if the first sample fails to meet the specifications. The Resident Engineer's staff is responsible for taking three samples of BC hot mix each day and delivering the samples to the district laboratory for testing. In addition, because of the timelag in receiving those test results from the district laboratory, the Resident Engineer's staff samples and performs gradation tests on the cold feed aggregate mixture used to manufacture BC. These tests, however, are only advisory and are not used for acceptance.

Six district laboratories perform daily extraction and gradation tests on the hot mix samples delivered by the Resident Engineer personnel. Again, as with PCC aggregate, usually only one sample from each group of three samples is tested. These gradation tests performed on the extracted aggregate then are used for acceptance by the Resident Engineer. The district laboratory also is responsible for monitoring the producer's gradation testing and performing verification tests. One verification gradation test is performed for each 5.4 Gg (6,000 tons) of each class of aggregate produced. Lack of correlation between the producer's tests and those of the district laboratory could increase testing requirements, prompt an immediate request for corrective action, and, in the worst case, shut down production.

The central laboratory primarily determines the physical characteristics of the aggregate materials, such as abrasion resistance, soundness, and specific gravity, to evaluate new sources of aggregate production, designate approved uses for aggregate from a particular source, and monitor aggregate quality in connection with construction projects. Tests to verify the physical characteristics of the aggregate are performed at least once per project. In addition, tests are performed in the central laboratory on BC hot mix samples provided by the district laboratories. These assurance tests serve as internal quality control on the testing procedures used by the district laboratories.

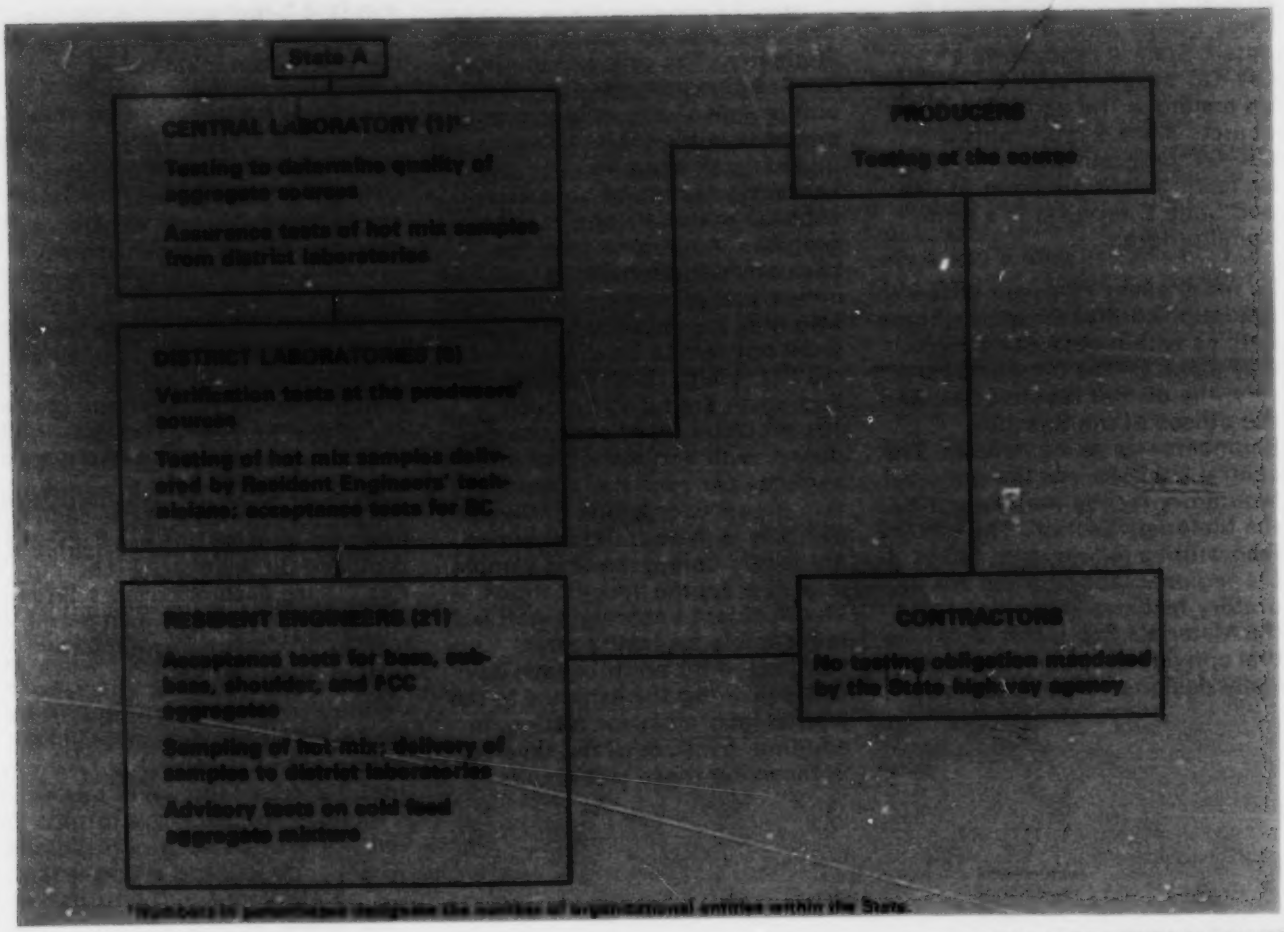
A schematic diagram of the State A program structure is shown in figure 2.

State B program

The aggregate gradation control program of State B is a QA–QC program with the construction contractor responsible for the quality control testing of aggregates. Aggregates are sampled at the "point of use"—the last point before being incorporated into their intended product. This point is the project site for base and subbase aggregate material and the concrete supplier's plant for aggregate used in PCC or BC. As a result, many construction contractors delegate the responsibility for aggregate gradation testing to their concrete suppliers, although the contractor still remains legally responsible. Quality control sampling and testing by the contractor's (or concrete supplier's) certified technicians is required at the rate of two aggregate samples per day for PCC used for pavements and one sample per day for PCC used for structures. For BC, two samples per day are taken for extraction and gradation testing. There are no requirements for gradation testing at the source, possibly because the State imports nearly 50 percent of the total aggregate used for highway construction. The program also incorporates statistical end-result specifications, including provisions for price adjustments, for the acceptance of products in which the aggregates are used.

Because the number of active Resident Engineers varies in relation to the number of active highway construction projects in the State, the number of personnel engaged in aggregate gradation testing activities also fluctuates. The Resident Engineer's staff does not engage in gradation testing except for aggregates used directly as base, subbase, or shoulder materials. Instead, the staff's aggregate gradation testing responsibilities are limited to monitoring the sampling and testing activities at the concrete suppliers' plants and to obtaining and delivering samples for verification testing to the district laboratories. At the concrete suppliers' plants, these verification samples are obtained by splitting

Figure 2.—Schematic diagram of State A program.


State A
CENTRAL LABORATORY (1)*
Testing to determine quality of aggregate sources
Assurance tests of hot mix samples from district laboratories
DISTRICT LABORATORIES (6)
Verification tests at the producers' sources
Testing of hot mix samples delivered by Resident Engineers' technicians; acceptance tests for BC
RESIDENT ENGINEERS (21)
Acceptance tests for base, subbase, shoulder, and PCC aggregates
Sampling of hot mix; delivery of samples to district laboratories
Advisory tests on cold feed aggregate mixture
PRODUCERS
Testing at the source
CONTRACTORS
No testing obligation mandated by the State highway agency

*Numbers in parentheses designate the number of organizational entities within the State.

the samples taken by the contractors' technicians at a frequency of one per day per class of PCC and one per day for the BC hot mix.

The State agency maintains nine district laboratories. All the samples for projects located within a district are received at the district laboratories, where the actual gradation testing is performed.

The central laboratory, involved in testing for approval of aggregate sources, does not participate in the aggregate gradation control program. However, the central laboratory does provide an internal quality control function for the gradation control program by periodically providing the district laboratories with "identical samples" for gradation testing, the results of which are used as a check on the testing procedures used by the district laboratories.

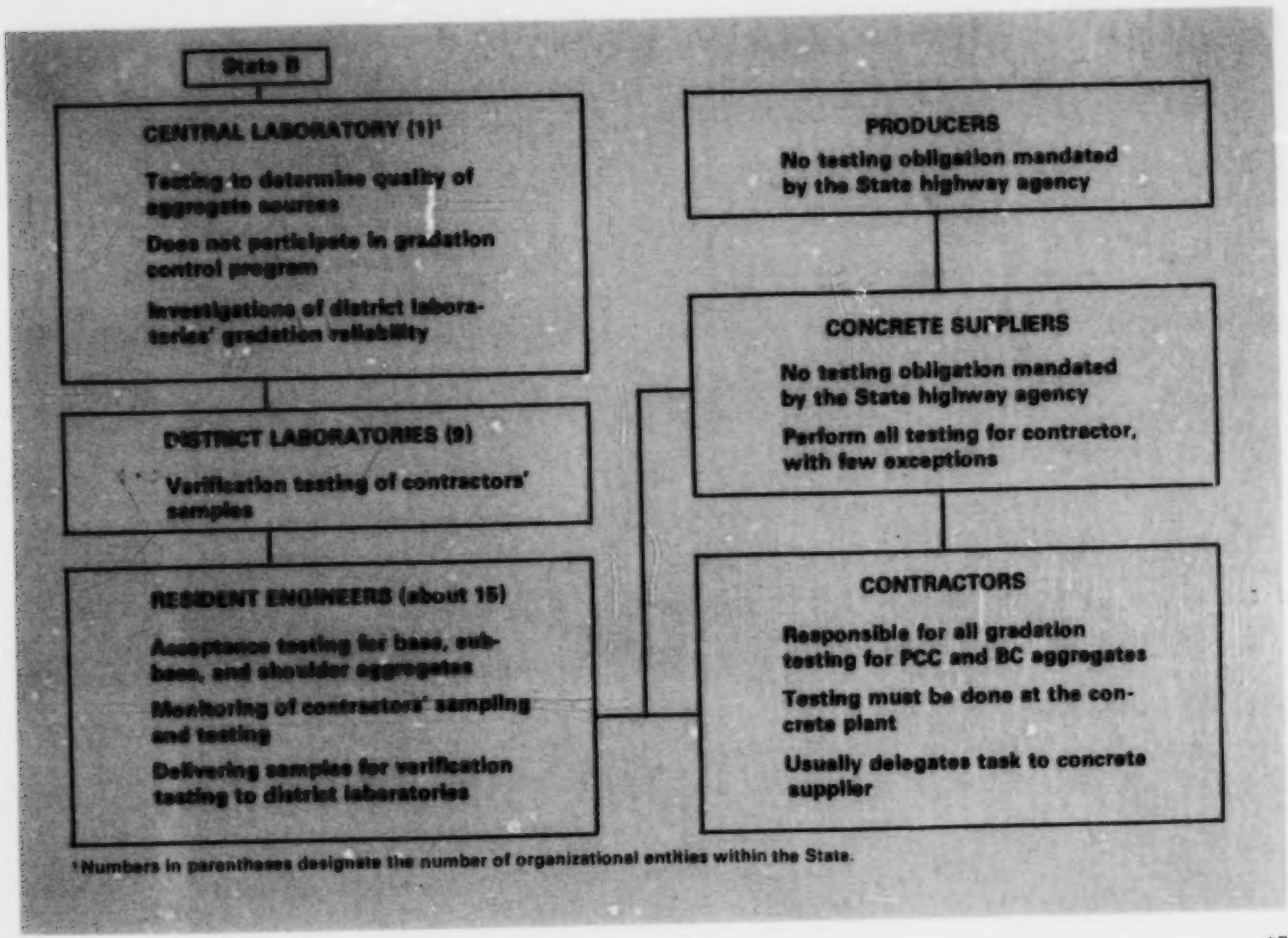
A schematic diagram of the State B program structure is shown in figure 3.

State C program

State C has a traditional program of aggregate gradation control; State personnel perform nearly all sampling and testing for aggregate gradation. Because of the particular geographic and demographic characteristics of the State, the program is administered differently in the rural areas than in the single large metropolitan area in the State. Accordingly, rural and urban areas are distinguished when presenting the corresponding program structures.

The majority of the State is rural. Here, samples for aggregate gradation testing are collected and tested by the Resident Engineer's staff. The actual sampling may be performed by employees of the contractor, the concrete supplier, or the producer under the direct supervision of the State inspector. The samples often are tested at the project site but also may be tested at the Resident Engineer's office or, if more conveniently located, at a district laboratory. In the rural areas, time spent transporting samples can be a significant portion of the total time spent in aggregate gradation testing activities. The State has 49 Resident Engineer offices, 36 of which fall in the rural category.

Figure 3.—Schematic diagram of State B program.


State B
CENTRAL LABORATORY (1)[1]
Testing to determine quality of aggregate sources
Does not participate in gradation control program
Investigations of district laboratories' gradation reliability
DISTRICT LABORATORIES (9)
Verification testing of contractors' samples
RESIDENT ENGINEERS (about 15)
Acceptance testing for base, subbase, and shoulder aggregates
Monitoring of contractors' sampling and testing
Delivering samples for verification testing to district laboratories
PRODUCERS
No testing obligation mandated by the State highway agency
CONCRETE SUPPLIERS
No testing obligation mandated by the State highway agency
Perform all testing for contractor, with few exceptions
CONTRACTORS
Responsible for all gradation testing for PCC and BC aggregates
Testing must be done at the concrete plant
Usually delegates task to concrete supplier

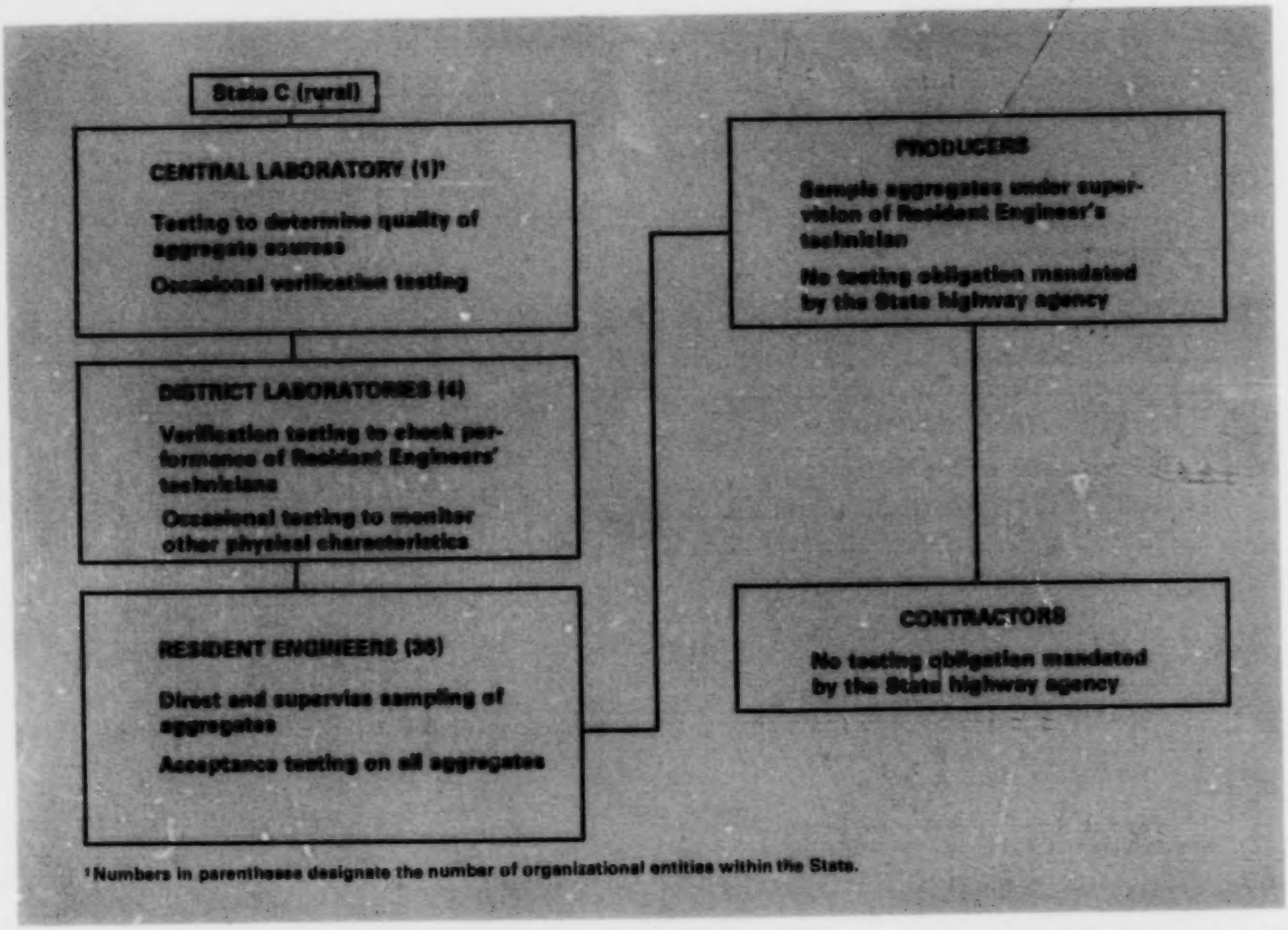
[1]Numbers in parentheses designate the number of organizational entities within the State.

Four of the five district laboratories are located in rural areas, and verification tests are primarily performed there. Such verification testing is a checking of results of tests performed by the State's own Resident Engineer's staff. Whenever possible, samples are provided for verification testing by splitting the samples collected by the Resident Engineer's staff, in which case the district laboratory technicians may collect such samples at the Resident Engineers' offices. In addition to performing gradation tests on the verification samples, several of the district laboratories are equipped to perform tests to determine other physical characteristics of the aggregates to monitor the quality of the aggregate after the initial qualification of a source.

Testing physical characteristics of the aggregate for qualification of new sources and annually conducting similar tests on aggregates from approved sources primarily are performed in the central laboratory. Occasional gradation tests on verification samples also are performed in the central laboratory. In addition, the central laboratory may perform unscheduled gradation tests whenever there is a recurrence of nonconforming gradations from a given source, as evidenced by the monitoring of verification test results.

The collection and testing of the primary quality control samples for aggregate gradation in the urban area differs from the method used in rural areas in that a branch of the Materials Section of the State agency is located within this metropolitan area. This branch assists the Resident Engineers' offices and the district laboratory in handling the greatly increased workload, which results because the urban area uses nearly 50 percent of the State's aggregate production. The responsibility for collecting and testing aggregate samples in the urban area primarily depends on the final aggregate product. The Resident Engineer's technicians collect and test all samples of aggregates to be used as base or subbase material and still assist in collecting and testing other samples. However, a district laboratory technician collects and tests all the BC hot mix samples, and a group of technicians employed by the branch of the Materials Section collects and tests

Figure 4.—Schematic diagram of State C program—rural area.


State C (rural)
CENTRAL LABORATORY (1)[1]
Testing to determine quality of aggregate sources
Occasional verification testing
DISTRICT LABORATORIES (4)
Verification testing to check performance of Resident Engineers' technicians
Occasional testing to monitor other physical characteristics
RESIDENT ENGINEERS (36)
Direct and supervise sampling of aggregates
Acceptance testing on all aggregates
PRODUCERS
Sample aggregates under supervision of Resident Engineer's technician
No testing obligation mandated by the State highway agency
CONTRACTORS
No testing obligation mandated by the State highway agency

[1] Numbers in parentheses designate the number of organizational entities within the State.

most of the PCC aggregate samples. Testing of verification samples is divided between the staff of the district laboratory and the staff of the Materials Section branch, jointly using the facilities of the district laboratory.

Schematic diagrams of the State C program structures for rural and urban areas are shown in figures 4 and 5.

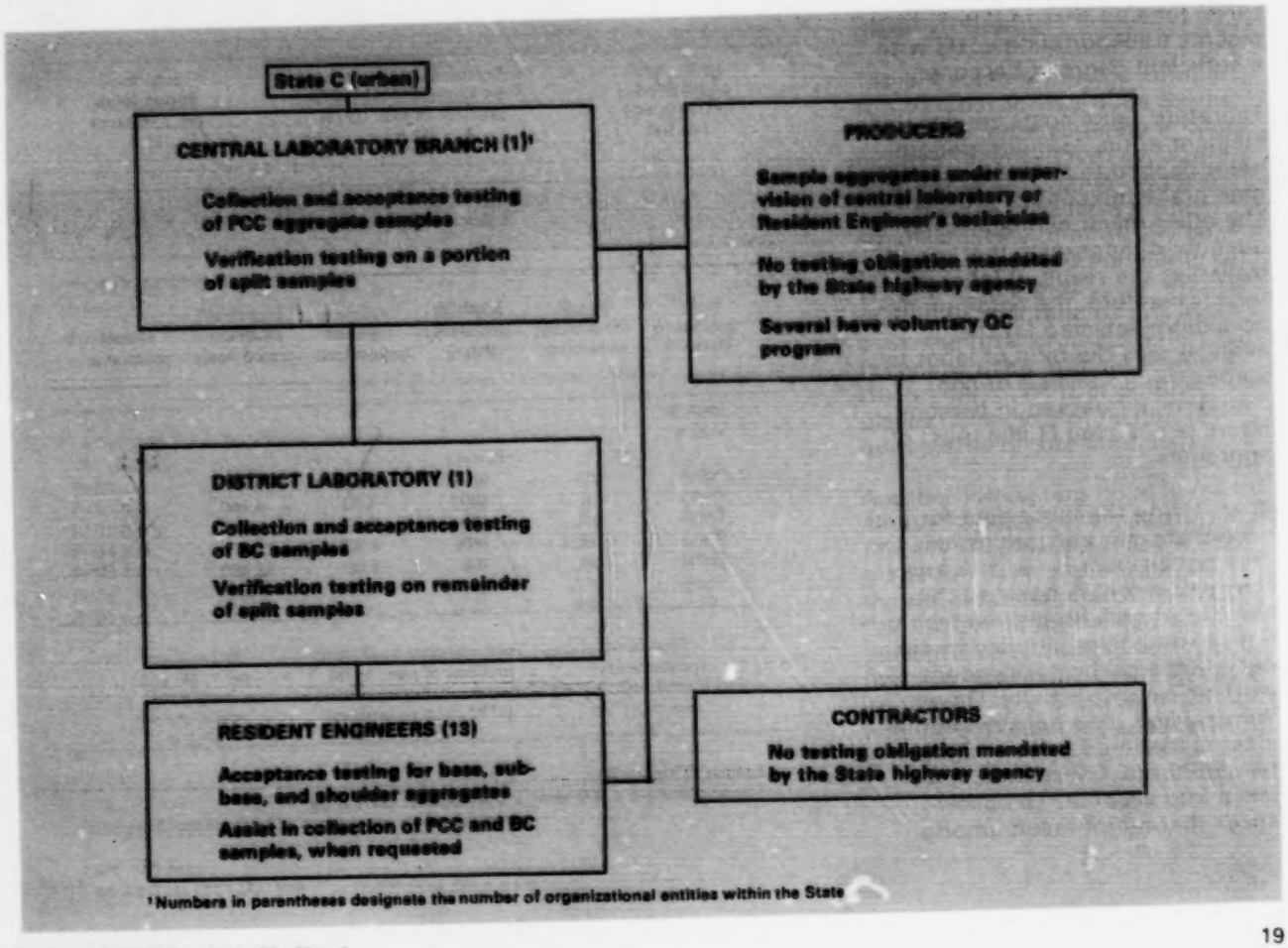
The required frequencies of testing for project control and verification depend on the aggregate's intended use. The project control tests are the primary quality control tests and are performed at the rate of one per 3.6 Gg (4,000 tons) of aggregate intended as subbase material; one per 1.8 Gg (2,000 tons) at the source plus one per 4.5 Gg (5,000 tons) at the project site for aggregate intended as base course material; one per 1.8 Gg (2,000 tons) at the plant plus one per 1.8 Gg (2,000 tons) at the project site for BC aggregates; and one per 1 223 m^3 (1,600 yd^3) of concrete for pavements and one per 765 m^3 (1,000 yd^3) of concrete for structures in the case of PCC aggregates. Verification tests are performed at the rate of one per project for subbase aggregates; one each at the source and at the project site per 36.3 Gg (40,000 tons) of base course aggregate; one per 3.6 Gg (4,000 tons) at the plant plus one per 9.1 Gg (10,000 tons) at the project site for BC aggregates; and one per 15 291 m^3 (20,000 yd^3) of concrete, regardless of use, for all PCC aggregates.

Comparison of Programs

An economic analysis was structured to compare the three States' programs. In structuring the analysis, a common denominator was sought to allow relative costs to be compared more easily by eliminating or minimizing variables such as hourly wages and production quantities.

Labor, equipment, facilities, and transportation costs were analyzed. It was determined that the only significant differences among the programs were in labor costs. The equipment used in

Figure 5.—Schematic diagram of State C program—urban area.


State C (urban)
CENTRAL LABORATORY BRANCH (1)[1]
Collection and acceptance testing of PCC aggregate samples
Verification testing on a portion of split samples
PRODUCERS
Sample aggregates under supervision of central laboratory or Resident Engineer's technician
No testing obligation mandated by the State highway agency
Several have voluntary QC program
DISTRICT LABORATORY (1)
Collection and acceptance testing of BC samples
Verification testing on remainder of split samples
RESIDENT ENGINEERS (13)
Acceptance testing for base, subbase, and shoulder aggregates
Assist in collection of PCC and BC samples, when requested
CONTRACTORS
No testing obligation mandated by the State highway agency
[1] Numbers in parentheses designate the number of organizational entities within the State

aggregate gradation testing is simple and relatively inexpensive; even a heavy-duty, motorized sieve shaker costs only a small fraction of a technician's annual wages. The total equipment costs for any of the programs investigated are not insignificant; however, the differences in cost are negligible when compared with labor costs. The same is true of the testing facilities. In most cases, aggregate gradation testing activities are conducted in one or two rooms of a building used for several other purposes. The overhead costs for such a small area also are insignificant relative to labor costs. Transportation costs, on the other hand, are comprised of the vehicles, the fuel, and the labor costs involved in travel time. The number of vehicles in use probably would not be significantly reduced by restructuring aggregate gradation control activities, and fuel costs would vary in direct proportion with the labor costs represented by the travel time. Accordingly, travel time, in person-hours, represents transportation costs with a sufficient degree of accuracy.

Therefore, labor costs are a major element of the common denominator needed to compare aggregate gradation control programs. The other major element is the quantity of aggregate that is controlled as the result of labor efforts. Therefore, the common denominator selected for the analysis was the ratio of labor to aggregate production or consumption, expressed in person-hours per 900 Mg (1,000 tons) of aggregate.

In analyzing the labor data for each State, the concept of full-time equivalents is used. A full-time equivalent is equal to the number of individuals involved in a given activity multiplied by the percentage of their time spent working on that activity. On an annual basis, one full-time equivalent is assumed to equal 2,080 person-hours. Overtime is not taken into account. The differences that might result among programs from including overtime are not considered significant and, in any event, determining what portion of the overtime should be allocated to aggregate gradation control activities virtually is impossible.

Labor estimates were derived by sampling the different entities and extrapolating results to all entities of the same kind within the given program. The validity of this economic analysis therefore is related to the validity of the extrapolation. For this reason, veri-

Table 1.—Labor used for aggregate gradation control in State A

Labor used by State highway agency

Entity	Number of technicians	Work in gradation testing	Full-time equivalents	Number of entities surveyed	Number of entities represented	Extrapolated full-time equivalents	Annual person-hours
		Percent					
Central laboratory	9	30	2.70	1	1	2.70	5,616
District laboratory	6	100	6.00	2	6	33.00	68,640
District laboratory	5	100	5.00				
Resident Engineer	7	40	2.80	1	21	58.80	122,304

Total labor (person-hours)	Total aggregate consumption (millions of tons, 1978)	Person-hours per 1,000 tons
196,560	12.8	15.4

Labor used by producers

Producer	Number of technicians	Work in gradation testing	Full-time equivalents	Annual person-hours	Annual production
		Percent			*Millions of tons*
P-A1	2	100	2.00	4,160	4.0
P-A2	5	60	3.00	6,240	4.0
P-A3	14	60	8.40	17,470	6.0
P-A4	6	100	6.00	12,480	3.5

Total labor (person-hours)	Total aggregate production (millions of tons, 1978)	Person-hours per 1,000 tons
40,350	17.5	2.3

1 ton = 0.9 Mg
1 person-hour per 1,000 tons = 1.1 person-hour per 1.0 Gg

fication was obtained from at least two different sources to insure that the entities sampled were representative of a particular State.

The total labor efforts expended for aggregate gradation control activities in States A, B, and C are calculated (in person-hours per 900 Mg [1,000 tons]) in tables 1–3. The State highway agency efforts are calculated separately from the producer/supplier/contractor efforts. It should be noted that the total aggregate production tonnage is the total for the sampled producers rather than a Statewide total. If the total aggregate production tonnage is not limited to highway aggregate and includes aggregate used in other States, this production tonnage may be larger than the State highway agency's total aggregate consumption tonnage, as in States A and C.

Although the three State programs investigated represent current applications of a particular approach to aggregate gradation control testing, it is still difficult to make generalizations from only three programs. Each State has a unique combination of aggregate sources, sampling frequencies, sampling locations, aggregate production and consumption quantities, and interactions among user agencies. The maximum value of the economic analysis would be realized if other States analyzed and compared their own aggregate gradation control programs with those of the three States.

Table 4 summarizes the comparison of labor for the three States. There is a large variation in State highway agency labor for aggregate gradation testing—a ratio of 18:1 between the largest and smallest levels of effort. By contrast, despite the dissimilarity of programs, the producers' efforts vary only by a ratio of 7:1. Moreover, the total producer effort is fairly low even in State A where the gradation control program places considerable testing requirements on the producers.

Another interesting point is the amount of labor expended by State A's highway agency on its gradation control program. Although this State implemented a QA–QC program, the State still performs considerable verification and acceptance testing. Lesser effort by the State would probably be sufficient for adequate gradation control.

Table 2.—Labor used for aggregate gradation control in State B

Labor used by State highway agency

Entity	Number of technicians	Work in gradation testing	Full-time equivalents	Number of entities surveyed	Number of entities represented	Extrapolated full-time equivalents	Annual person-hours
		Percent					
Central laboratory	—	0	0	1	1	0	0
District laboratory	2	100	2.00	2	9	18	37,440
District laboratory	2	100	2.00				
Resident Engineer	2	30	0.60	1	15	9	18,720

Total labor (person-hours)	Total aggregate consumption (millions of tons, 1978)	Person-hours per 1,000 tons
56,160	20	2.8

Labor used by producers (suppliers)

Producer	Number of technicians	Work in gradation testing	Full-time equivalents	Annual person-hours	Annual production
		Percent			*Millions of tons*
P–B1	2	20.0	0.40	830	4.00
P–B2	5	12.5	0.63	1,310	1.10
P–B3	1	12.5	0.13	270	0.20
P–B4	5	20.0	1.00	2,080	2.00
P–B5	0	0	0	380[1]	0.50
P–B6	2	12.5	0.25	520	0.05
P–B7	1	40.0	0.40	830	0.10

Total labor (person-hours)	Total aggregate production (millions of tons, 1978)	Person-hours per 1,000 tons
6,220	8	0.8

[1] Estimated annual effort by commercial testing laboratory.

1 ton = 0.9 Mg
1 person-hour per 1,000 tons = 1.1 person-hour per 1.0 Gg

Table 3.—Labor used for aggregate gradation control in State C

Labor used by State highway agency

Entity	Number of technicians	Work in gradation testing	Full-time equivalents	Number of entities surveyed	Number of entities represented	Extrapolated full-time equivalents	Annual person-hours
		Percent					
Rural areas							
Central laboratory	2	75	1.50	1	1	1.50	3,120
District laboratory	2	20	0.40	1	4	8.00	3,328
Resident Engineer	2	30	0.60	2	36	28.80	59,904
Resident Engineer	2	50	1.00				
Urban area							
Central laboratory branch	PCC 7	25	1.75	1	1	1.75	3,640
District laboratory	BC 1 3	100 40	1.00 1.20	1	1	2.20	4,576
Resident Engineer	2	20	0.40	1	13	5.20	10,816

Total labor (person-hours)	Total aggregate consumption (millions of tons, 1978)	Person-hours per 1,000 tons
66,352 (rural)	0.85 (rural)	78.1 (rural)
19,032 (urban)	0.85 (urban)	22.4 (urban)
85,384	1.7	50.2

Labor used by producers

Producer	Number of technicians	Work in gradation testing	Full-time equivalents	Annual person-hours	Annual production
		Percent			*Millions of tons*
P–C1	2	20	0.40	830	2.5
P–C2	1	25	0.25	520	1.3
P–C3	1	25	0.25	520	2.0
P–C4	2	30	0.60	1,250	1.0
P–C5	2	25	0.50	1,040	1.0
P–C6	3	33	1.00	2,080	1.3

Total labor (person-hours)	Total aggregate production (millions of tons, 1978)	Person-hours per 1,000 tons
6,240	18.2[1]	0.3

[1]Production tonnage has been doubled to include producers in rural areas who generally do not have QC programs.

1 ton=0.9 Mg
1 person-hour per 1,000 tons=1.1 person-hour per 1.0 Gg

All three States reported good aggregate quality resulting from their gradation control programs. Although quality is subjective and aggregate acceptable in one State might be unacceptable in another, it would appear that adequate quality can be maintained with any of the programs examined. At least for the levels of effort presently being expended in gradation control, it cannot be shown that the product quality resulting from different programs varies significantly.

The analysis indicates that the traditional program of State C is approximately three times more expensive than the producer-oriented program of State A and almost 15 times more expensive, in terms of person-hours per 900 Mg (1,000 tons), than the contractor-oriented program of State B. It was not known until after the detailed field investigation was underway that the total annual aggregate consumption in State C was much lower than in the other two States. Nevertheless, it would take a threefold increase in aggregate consumption, without increase in labor, for the traditional program to yield costs comparable to those of the producer-oriented program. The increase in consumption would have to be almost 15 times as large to arrive at costs similar to the contractor-oriented program. Such consumption increases could not be handled feasibly without significantly increasing labor.

The high labor effort expended by State C's highway agency is partly because of travel time involved in collecting samples in the rural area of the State. The urban area of State C, which may be more representative of many States, has a considerably lower labor effort. Nevertheless, the urban area effort is still higher than the efforts of the other two States. It can thus be concluded that both urban and rural States using traditional programs can benefit through a QA–QC program, especially rural States that can decrease sample collection travel time by adopting producer- or contractor-oriented programs.

Table 4.—Comparison of labor for States A, B, and C

State program	Person-hours per 1,000 tons: State highway agency	Person-hours per 1,000 tons: Producers	Total person-hours by State highway agency
A	15.4	2.3	196,560
B	2.8	0.8	56,160
C	50.2	0.3	85,384

1 ton=0.9 Mg
1 person-hour per 1,000 tons=1.1 person-hour per 1.0 Gg

Impact of a QA–QC Program

In addition to considering costs, the impact of a QA–QC program must be examined. For the State highway agency, the cost savings represent the most immediate tangible benefit; however, the substantial although intangible benefit of avoiding potential liabilities from the State's performance of quality control tests on intermediate products should not be underemphasized.

A QA–QC program with the contractor fully responsible for the quality of aggregate used in construction also should offer significant advantages to the contractor. Although most of the cost for gradation testing is absorbed by the contractor, actual costs are relatively low, as substantiated by the relatively small differences in producer/supplier cost data derived from the three States investigated. In addition to low costs, test results are always immediately available, allowing more timely adjustments to be made. Also, by being responsible for testing, contractors can better monitor their contractual relationships with the producers for quality control. Contractors face additional costs and responsibilities under QA–QC programs, but most contractors surveyed during the investigations of the States using such programs indicated that they were satisfied with the QA–QC approach used in those States. It has not yet been demonstrated whether a small contractor has greater initial difficulty than would a large contractor in establishing an aggregate gradation control program.

Implementation of a QA–QC program probably would have a significant impact on aggregate producers and concrete suppliers, because in most cases contractors would delegate the responsibility for testing. On the other hand, aggregate producers and concrete suppliers, unburdened by State-mandated quality control programs, could perform only the testing they felt necessary to achieve adequate process control for the characteristics of their particular aggregate and their particular facility. In this manner, the cost to the producer and supplier would represent a voluntary quality control effort dictated by market forces, not one imposed by the State.

Consumers in local and county jurisdictions may be adversely affected by a QA–QC program if they are relying on the State's efforts for aggregate gradation control for their own projects. However, by using their own QA–QC approach, those agencies could minimize their own effort for adequate quality assurance. They would have to carry their own share of the aggregate gradation control costs rather than being subsidized by the State. At the same time, local and county agencies may find that the implementation of a QA–QC program by the State results in a better quality product for their own projects because of the improved process control by the contractor.

Summary

This article describes detailed economic analyses of aggregate gradation control programs in three States. Other States are encouraged to perform a similar analysis of their own program and make comparisons. Although each State's program is unique, conclusions can be drawn about relative costs of the kinds of programs. The cost of aggregate gradation control is lowest where the State highway agency does not involve itself in process control testing. Although process control should be exercised at various steps in the production, transportation, and handling of the aggregate, it is not efficient for the State highway agency to do such testing.

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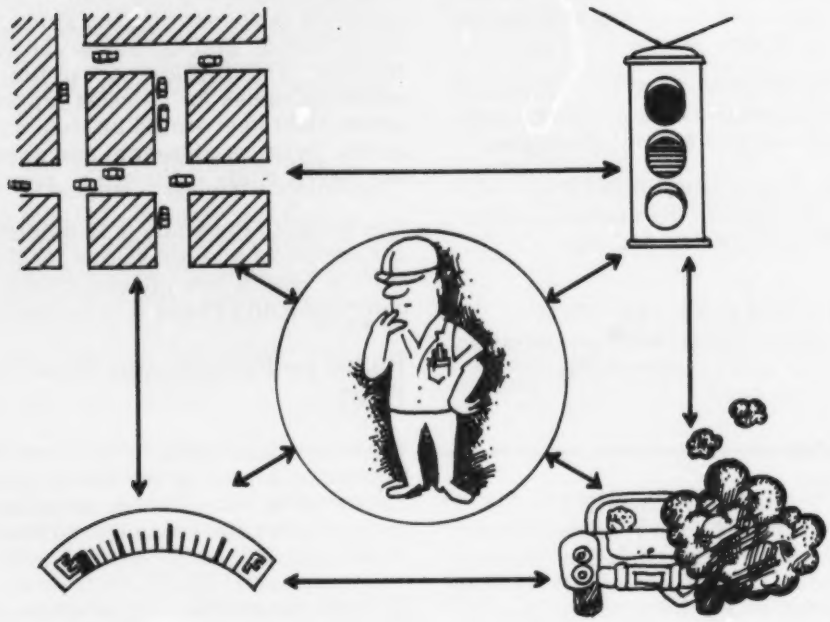
Update of the Fuel Consumption and Emission Values in the NETSIM Traffic Simulation Model

by
Alberto J. Santiago



Introduction

In the United States it has been estimated that all modes of highway transportation account for 74 percent of the total transportation energy and 45 percent of all U.S. fuel consumption. (*1*)[1] Additionally, it has been estimated that highway transportation accounts for 50 percent of the total annual emissions of air pollutants such as carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides, and particulates. (*2*) These statistics dramatically demonstrate the seriousness of the energy and environmental problems related to highway transportation.

The Problem

The problem is very simple to state: "How can we reduce fuel consumption and emissions from vehicles operating on a street network?" Unfortunately, the answers are quite complex.

To resolve this problem a dual approach is required. First, we need cleaner and more energy-efficient vehicles; second, we need a means of accurately estimating and predicting fuel consumption and emissions from vehicles operating on a network to assess accurately the energy and environmental impacts of traffic control strategies and roadway designs.

Breakthroughs in technology, achieved by automotive engineers, have provided the means for manufacturing cleaner and more efficient vehicles. Today, automobiles averaging 12.8 to 17.0 km/L (30 to 40 miles per gal) are common, and all automobiles manufactured and sold in the United States have some kind of emission control system to insure environmental protection. The problems still remaining for the traffic engineer are how to predict vehicular fuel consumption and emissions in a given operating environment and how to enhance roadway designs and traffic control strategies to provide an environment where vehicles can operate more efficiently.

In response to these problems, the Federal Highway Administration (FHWA) and others have developed computer programs to evaluate geometric designs

[1] Italic numbers in parentheses identify references on page 29.

and traffic control strategies (primarily for urban areas) from environmental and energy conservation standpoints. Extensive use of these models has demonstrated their potential as effective tools in the development of traffic engineering measures that reduce (1) motorist operating costs; (2) fuel consumption; (3) costs associated with planning, designing, and implementing new traffic control strategies; and (4) costly and inconvenient retrofits when problems in a strategy are detected only after implementation. These computer programs can be categorized into three major groups:

- Simulation models (NETSIM, TRAFLO, TRANSYT, SIGOP)—simulate the performance of traffic under a given set of geometrics and control strategies.

- Optimization programs (SOAP, PASSER, MAXBAND, TRANSYT[2], SIGOP[2])—optimize traffic signal settings by reducing delay and fuel consumption.

- Control programs (UTCS Enhanced, UTCS Extended)—control traffic signal settings based on traffic flow fluctuations and/or time-of-day operation on a real-time basis.

The NETSIM Model

This article focuses primarily on the NETSIM simulation model, which is the most sophisticated of the current traffic models. By using this model, engineers can test and evaluate a range of feasible traffic control strategies and geometric designs quickly, efficiently, and economically. NETSIM simulates the operations of urban traffic by generating the trajectory of each type of vehicle—automobiles, trucks, and buses—in the system as it traverses a specified network of urban streets (links) and intersections (nodes). Each such vehicle responds to local conditions, primarily the signal control and the influence of neighboring vehicles. At the conclusion of each second of simulated time each vehicle's position, speed, and acceleration are determined. (*3, 4*) This 1-second resolution permits highly accurate simulations of traffic flow in an urban network.

As an output, NETSIM estimates vehicular fuel consumption and emissions for the condition modeled based on a series of tables embedded in the program. These tables, developed in 1976, represent the vehicular fuel consumption and emissions of the 1971 vehicle fleet and were derived from computer simulations of engine performance. (*3, 5*) However, fuel consumption and emissions calculations are limited because the number of tables in NETSIM is restricted to one per vehicle type. This implies that tables used by the model have to be representative of the vehicle population within the vehicle type.

The energy crises of 1973–1974 and 1979, in addition to the Clean Air Act Amendments of 1977, triggered changes in vehicle manufacturing policy. New vehicles were to be smaller, lighter, cleaner, and most important, more energy efficient. In a short time, these changes have made the fuel consumption and emission tables in NETSIM obsolete.

FHWA, recognizing the need to update the tables, currently is sponsoring the study "Fuel Consumption and Emission Values for Traffic Models." The development of fuel consumption and emission tables for vehicles representative of the entire 1980 fleet would be time consuming and costly. Because of budget and personnel limitations, the FHWA study is limited to passenger vehicles.

The scope of the study is to determine vehicular fuel consumption and emissions for the passenger vehicle fleet in two phases. Phase I is already completed and Phase II is currently underway.

Phase I—Present and Near Future Vehicle Fleet

The main objectives of this phase were to define the present and near future passenger vehicle fleet and to determine the vehicles for which fuel consumption and emission tables should be developed.

To make the project cost effective, the boundaries of the time frame defining "current" and "near future" had to maximize the period of time for which the fuel consumption and emission tables would be valid. Based on this constraint, 1979 was selected as the lower boundary and 1985 as the upper boundary for the following reasons:

- Between 1975 and 1977 vehicle manufacturers responded to the energy crisis of 1973–1974 by manufacturing more fuel-efficient vehicles than those manufactured before 1973. Unfortunately, this manufacturing policy started to fade in 1976 and 1977, and by 1979 most vehicles manufactured in the United States were eight-cylinder engined vehicles. (*6*)

- In 1979 a second energy crisis convinced the U.S. vehicle manufacturing industry and the general public of the severity of the energy problem.

- As of May 1981 none of the manufacturers of vehicles sold or manufactured in the United States had developed product plans beyond 1985. (*7*)

After determining that 1979–1985 would define the current and near future passenger vehicle population, all the passenger vehicles that were and will be manufactured and sold in the United States (including domestic and foreign) during that time were investigated. These vehicles were defined by

[2]Contain simulation capabilities.

engine size (displacement) and engine-drivetrain combination (engine and transmission) instead of by model because of the availability of different engine sizes and transmissions within the same vehicle model.

The 1979–1985 passenger vehicle population was divided into two groups—the 1979–1981 population and the 1982–1985 population. The 1982–1985 population was defined in terms of the 1979–1981 population so that fuel consumption and emission maps (graphical representations of the relationships between variables that affect fuel consumption and emissions) could be developed for the nonexistent vehicles.

From an analysis of the 1979–1981 passenger vehicle population, 57 engine sizes were identified ranging from 1.1 to 6.0 L of displacement (70 to 368 in^3 of displacement). These engines were in 176 vehicle models, yielding over 500 engine-drivetrain combinations (transmissions were classified as automatic or manual and by the number of forward gears). (*6*, *8*) Of these 500 engine-drivetrain combinations, over 350 combinations will be available between 1982 and 1985. (*7*)

It is not cost effective to develop fuel consumption and emission maps for over 350 engine-drivetrain combinations, so accurate sales figures[3] were used as weighting factors to determine the "most common" combinations in the 1979–1985 passenger vehicle population. (*6*, *7*) From an analysis of these data, 21 engine-drivetrain combinations were identified to account for 74 percent of the 1979–1985 passenger vehicle population.

Because of budget limitations, 15 of the 21 engine-drivetrain combinations will be selected for testing in Phase II (table 1). In the worst case, where the 15 combinations selected for testing are the "less common," the resulting fuel consumption maps will be representative of 57 percent of the 1979–1985 passenger vehicle population. In the best case, where the 15 combinations selected are the "most common," the resulting fuel consumption maps will be representative of 66 percent of the 1979–1985 passenger vehicle population. Maximizing the percentage of representation will be attempted; however, the final selection of vehicles will depend on their availability from rental and leasing agencies.

The development of a fuel consumption and emission table representative of the entire automobile fleet requires that individual tables be developed for different categories, such as four-, six-, and eight-cylinder vehicles, and subsequently pooled using sales figures as weighting factors. The resulting table is statistically representative of the automobile fleet.

[3]Confidential figures submitted by the vehicle manufacturers to the National Highway Traffic Safety Administration for Corporate Automobile Fuel Economy certification.

Table 1.—Engine-drivetrain combinations to be representative of the 1979–1985 passenger vehicle population

Engine size	Cylinders	Transmission[1] and number of forward gears
Cubic inches of displacement		
90	4	A3 and M5
97	4	A3 and M4
105	4	A3 and M5
107	4	A3 and M5
108	4	A3 and M5
140	4	A3 and M4
151	4	A3
156	4	A3
173	6	A3
200	6	A3
229	6	A3
231	6	A3
267	8	A3
302	8	A4
350	8	A3

[1] A=automatic; M=manual.
1 in^3=0.016 L

Projections indicate that if the vehicle manufacturers remain relatively close to the 1981–1985 product plans developed in 1981, the tables to be developed in Phase II will be valid until 1992. This rationale is based on the fact that tables will be developed for 15 engine-drivetrain combinations, and by using the pooling procedure discussed above, updates could be made without having to develop additional tables.

Phase II—Development of Fuel Consumption and Emission Maps

The objective of this phase is to develop accurate fuel consumption and emission tables for 15 of the 21 engine-drivetrain combinations specified in Phase I. These tables will be derived from fuel consumption and emission maps developed, to the extent possible, from field experimentation.

In the past, research has been oriented toward developing fuel consumption and emission maps from computer simulations of engine performance or chassis dynamometer testing. These approaches produce accurate maps that describe the performance of the engine *exclusively* and not the performance of the vehicle as it operates on the road. This, then, justifies developing maps from field experimentation.

Following are discussions on the procedures to be used in Phase II of this research study and the expected results.

Development of fuel consumption maps

Three systems—the engine, the vehicle (which includes body and engine), and the driver—must be analyzed in detail to assess vehicular fuel consumption. Only the first two systems will be discussed in this article because the driver (the system that controls the operation of the engine and vehicle) is simulated by the model. NETSIM calculates the speed and acceleration of the vehicle using car-following algorithms derived from driver behavior. Fuel consumption is then derived from the modeled speeds and accelerations. This implies that the fuel consumption maps to be developed in this study must cover the range of speeds and accelerations that the vehicles are capable of so that fuel consumption can be accurately estimated for any given driving cycle.

The engine and the vehicle must be analyzed as two separate systems because the engine is the element that actually consumes fuel and the vehicle is the medium by which loads are applied to the engine. This analysis encompasses the development of the following two separate data bases that describe fuel consumption from each system.

- A data base developed through chassis dynamometer tests relating fuel flow to engine revolutions per minute (RPM) and manifold vacuum. This data base will describe the engine.
- A road-test data base relating vehicle speed and acceleration to engine RPM, manifold vacuum, fuel flow, and operating temperatures for each gear. This data base will describe the vehicle.

Maps derived from chassis dynamometer testing are extremely useful because fuel flow rate is identified uniquely by engine RPM and manifold vacuum independent of the secondary effects of temperature and atmospheric pressure on the combustion efficiency itself. The resultant maps are independent of driveline efficiencies, lubricant temperatures, and rolling resistance because any changes in these parameters will change the manifold vacuum pressure at a given RPM.

These dynamometer maps are necessary because in carbureted engines it is not possible to measure fuel flowing into the engine itself without extensive modifications to the carburetor. If carried out, these modifications may affect the operating characteristics of the engine. Therefore, only the fuel flowing into the carburetor can be measured.

At low speeds and high accelerations, the combined effects of fuel sloshing in the carburetor bowl and the timelags induced by the filtering effects of the bowl make it impossible to draw any conclusions concerning fuel flow rate into the engine. On the dynamometer, fuel sloshing effects are negligible, as it is possible to remain at any operating point sufficiently long to overcome the filtering effects of the carburetor bowl.

On-road testing of vehicles is necessary to assess vehicular fuel consumption in the vehicles' operating environments. These tests consist of fully instrumenting each vehicle and driving it through all possible combinations of speed and acceleration until sufficient data have been collected to characterize fully the behavior of the vehicle. To obtain statistically valid results, the tests are repeated several times randomizing the order of the individual runs to prevent any systematic bias in the recorded data.

The instrumentation installed in the vehicles consists of the data logger, which samples and records data, fifth wheel assembly, inclinometer, electronic tachometer, pressure transducers, electrical thermocouples, fuel flow meter, and power supply.

The data logger records each data element every 0.05 seconds on a cassette tape that is later analyzed in a computer. The fifth wheel assembly measures distance, speed, and acceleration, and the inclinometer measures road grades to correct the acceleration readings to what they would have been on a level road. The electronic tachometer, pressure transducers, and electrical thermocouples measure engine RPM, vacuum pressure, and engine temperature, respectively. The equipment weighs approximately 68 kg (150 lb) and fits in the rear passenger area of a vehicle.

On-road tests will be conducted on an airport runway because of the safety advantages over conducting the tests on public roads. The tests require that fuel consumption data for high speeds and abrupt accelerations must be collected, and this might be hazardous if carried out on public roads. Additionally, conducting the tests on a smooth, leveled pavement increases the accuracy of the data collected by the fifth wheel assembly. Bumps, cracks, potholes, and joints in pavements make the fifth wheel bounce, resulting in erroneous measurements of speed, acceleration, and distance.

Subsequently, the data bases generated by the dynamometer testing and the on-road testing are merged and run through statistical mapping procedures to produce maps that relate fuel flow rate to the vehicles' speed and acceleration for each available gear.

Development of emission maps

The relatively long response times of current emission analyzers coupled with their bulk, weight, and high power requirements relegate any testing program to one of steady-state determinations on a chassis dynamometer. In this study, it is anticipated that test procedures for hydrocarbon and carbon monoxide emissions can be developed that are analogous to and compatible with those used for the fuel consumption tests. That is, if each engine

operating point, as defined by engine RPM and manifold vacuum, determines the emission rates of the vehicle[4], then emission maps can be developed on the dynamometer that can be linked to on-road performance through measurements of the determining factors in an on-road test in a manner similar to the methodology used in developing the fuel consumption maps.

Summary and Recommendations

From a transportation perspective, the scenario for the 1980's is restricted by energy and environmental concerns. The era of abundant energy supplies is past, and reducing air pollution is imperative. It is time to work with greater commitment and urgency toward implementing environmentally safe and energy-efficient solutions.

Future research should be oriented toward developing fuel consumption and emission maps for trucks and buses in a manner similar to the one described in this article. Also, efforts should be directed toward developing feasible roadway design practices that would provide an operating environment where vehicles could operate efficiently.

To cope with environmental and energy problems, major traffic engineering actions, requiring accurate analysis tools, must be planned and pursued aggressively over many years. The successful completion of this study will update and improve the capabilities of the NETSIM model in accurately estimating fuel consumption and emissions from passenger vehicles in an urban network. This enhancement will provide the traffic engineering community with a powerful tool for developing, testing, and evaluating traffic control strategies in addition to determining the environmental and energy impacts of such strategies in an urban setting.

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[4]Subject to verification through this study.

[5]Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Grade Severity Rating System

by

Paul Abbott

Introduction

Many research projects have focused on the causes of heavy truck accidents on downgrades and on countermeasures for these accidents. (*1–4*)[1] Despite the money and time expended on such research, no fully satisfactory countermeasures have been developed; the effectiveness of various countermeasures is not known nor is it known which countermeasures work best in given situations. The lack of accurate information about the effectiveness of a countermeasure has hampered the efforts of design and safety engineers to minimize the adverse effects of downgrades on heavy trucks and to choose appropriate countermeasures for different situations.

States have tried various advisory signs, which are intended to prevent accidents by giving drivers information on the percent of downgrade slope, length of hill and degree of slope, use of a lower gear, and downgrade configuration (fig. 1). In addition to signs, brake inspection areas (fig. 2) have been constructed at the crests of hills, and some States require that drivers of heavy trucks stop at these areas. Another countermeasure that has received increasing attention in recent years is the escape ramp (fig. 3).

All of these countermeasures have advantages and disadvantages. For example, escape ramps are effective only if drivers are willing to use them and if the ramps can be built to adequate design standards on terrain surrounding the downgrade. Signs are inexpensive and easy to install but are effective only if drivers understand and follow the advice.

As a result of continuing interest in truck downgrade accident prevention and the lack of information on preventing or mitigating such accidents, the Federal Highway Administration (FHWA) initiated research in 1977 to investigate heavy truck downgrade accident problems and develop a grade severity rating (GSR) model to determine the severity of a downgrade and a method of informing truck drivers of the best gear for descending a specific downgrade. (*5, 6*)

This research initiated further study to determine the most effective advisory sign by testing in a simulator a set of weight-specific speed signs and developing criteria for road testing the most effective sign.

[1] Italic numbers in parentheses identify references on page 34.

History of Grade Severity Rating Models

One of the first GSR models, proposed in the early 1960's, expanded the three U.S. Bureau of Public Roads grade categories into 10 categories with finer distinctions between grades based on grade length and degree of slope. (*7*)

In 1975 another GSR model introduced the following important new ideas: (*8*)

- The concept of rating hills by their effect on a representative truck.
- The inclusion of the effect of hill length by considering brake fade effects.
- The use of a stopping distance criterion as a measure of available braking capacity.

This model, based on the "work energy theorem," applied to braking on a grade. The work energy theorem equation can be solved for the descent speed, which will allow stopping in a criterion distance. To use the equation, the total retarding force must include brake and nonbrake terms. The brake terms for unfaded brakes were derived from field test results and modified for fade effects using a brake fade factor. (*7, 8*) This brake fade correction was derived from temperature measurements made during brake dynamometer tests. To use the brake fade factor, the concept of brake equivalent time—hill descent time multiplied by the percent brake use—was introduced.

Limitations in the model because of a lack of knowledge of the effects of nonbrake forces and the effects of brake fade prevented this from being a functional GSR model. Research indicates driver inexperience, failure to downshift, and inadequate signing can be affected by informational signs, and therefore these factors essentially define the requirements for a functional GSR model.

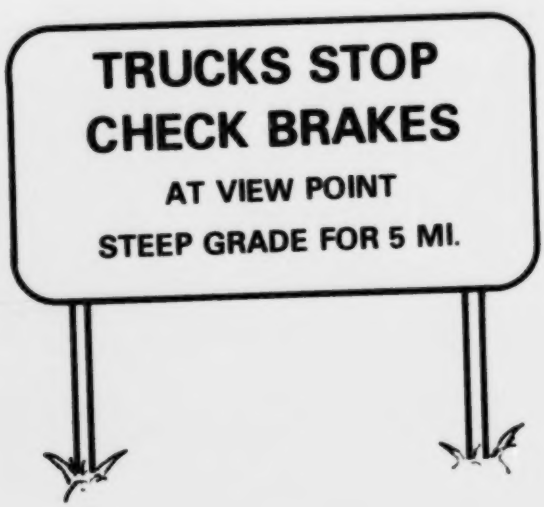
Development of a Grade Severity Rating Model

Developing a standard method of rating downgrades based on grade severity requires an in-depth understanding of the relationships among speed, brake usage, vehicle weight, and brake fade. This is complicated by the fact that hills having entirely different geometric characteristics may place the same braking requirements on vehicles. For instance, a 7 percent 11.3 km (7 mile) downgrade may place the same total braking load on a vehicle as a 9 percent 6.4 km (4 mile) downgrade and, thus, may require the same initial speed for a safe descent. Further, downgrades are not always constant nor continuous. A grade might be 9 percent for 3.2 km (2 miles) and 5 percent for 11.3 km (7 miles); another grade might be 8 percent for 4.8 km (3 miles), level for 1.6 km (1 mile), and 6 percent for 11.3 km (7 miles). All of these grade configurations might place the same braking requirements on a vehicle. The GSR model overcomes this problem by allowing each downgrade to be rated according to its specific characteristics.

Research indicated that determining how to measure brake effectiveness was necessary before a functional GSR model could be developed. Computer simulation and field testing were used to collect data on the effect of truck weight, length and slope of downgrade, and truck speed on brake fade and brake effectiveness. Field testing was done on both level roads and downgrades using a calibrated 34.3 Mg (75,650 lb) truck with a retarder (engine brake). After initial testing, truck brake temperature was determined to be the most important factor to consider in developing a GSR model so subsequent field testing concentrated on collecting these data. A speed brake temperature prediction model was developed.

Figure 1.—Standard downgrade advisory signs.

Figure 2.—Combined advisory sign for brake test area and grade severity.



The model was field tested on seven downgrades in the Western United States using a single instrumented truck. Brake temperatures were predicted for the test vehicle and compared with the actual tested brake temperatures. The correlation coefficient between predicted and actual brake temperatures was 0.85.

In another field test, 25 randomly selected trucks were tested on the Grapevine, a downgrade on I–5 south of Bakersfield, Calif. Using the speed brake temperature prediction model, the brake temperature at the bottom of the downgrade was calculated based on truck weight, brake temperature at the start of the descent, vehicle speed on the grade, and length and degree of slope. The correlation coefficient between the predicted and actual temperatures at the bottom of the grade in this test was 0.81.

As a result of field tests on both level roads and downgrades and an analysis of truck transmission characteristics and associated engine braking forces, a model was developed to determine the maximum safe descent speeds for beginning a grade for specific weight trucks. A safe descent speed is that speed at which the driver can maintain control of the truck without having to apply more than 44.5–66.7 N (10–15 lb) brake pressure for the length of the grade. This enables the brakes to dissipate the heat caused by braking without overheating, thus allowing the truck to maintain constant speed on the downgrade and to stop on the downgrade.

Figure 3.—Example of a gravity escape ramp (top). Example of a gravel escape ramp (bottom).

The Grade Severity Rating System

The Grade Severity Rating System (GSRS) includes the process of determining the severity of a grade, a method of calculating a safe descent speed for a truck of a specific weight, and a means of conveying the weight-specific speed information to the truck driver.

The relationship among truck speed, engine speed in revolutions per minute (RPM), and transmission gears is important in developing a GSRS. Heavy trucks are designed so that they operate within a narrow band of engine RPM's. The driver learns to maintain a specific vehicle speed by matching engine speed with the appropriate gear. Thus, an experienced driver, when given a slower speed to drive, immediately recognizes the appropriate gear and slows down by downshifting until the correct gear is reached. A driver with little experience in a specific truck would not know the exact gear to use but would go through the same procedure of slowing down and downshifting until the appropriate engine and vehicle speeds were reached, at which time the truck would be in the appropriate gear.

Initial research indicated that it was possible to assign a downgrade a grade severity rating from 1 to 9 based on length and degree of slope. A truck of a specific weight could safely negotiate different hills having the same severity rating.

To implement a GSRS an "in-cab-truck specific gear selection model" had to be developed. This was complicated by the number of combinations of transmissions, weights, and hills and the complexity of the calculations a driver would have to make to select the

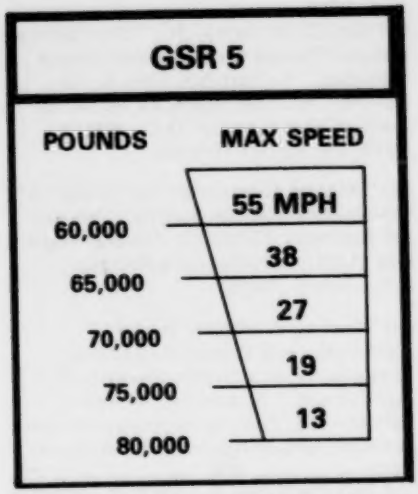


Figure 4.—Combined grade severity rating and weight-specific speed sign.

proper speed given such data as truck weight and severity rating. As the research progressed, it became apparent a trade-off existed between giving every driver of every weight truck enough information to determine maximum safe descent speed and correct gear and developing a system that could be used under actual operating conditions.

As a result, the grade severity rating sign was combined with a weight-specific speed sign (fig. 4) allowing the truck driver to select the appropriate gear for descending a specific hill based on the grade severity rating of the hill and recommended speed based on vehicle weight and transmission characteristics. Although this approach to developing the GSRS is different from the in-cab gear selection approach discussed above, it provided the truck driver with information necessary to drive safely on downgrades.

Development of Weight-Specific Speed Signs

A primary consideration in developing a usable GSRS is the number of weight ranges that should be used—the more weight ranges, the more specific the weight speed information. Too many weight ranges, however, would make the GSRS sign confusing and difficult to use.

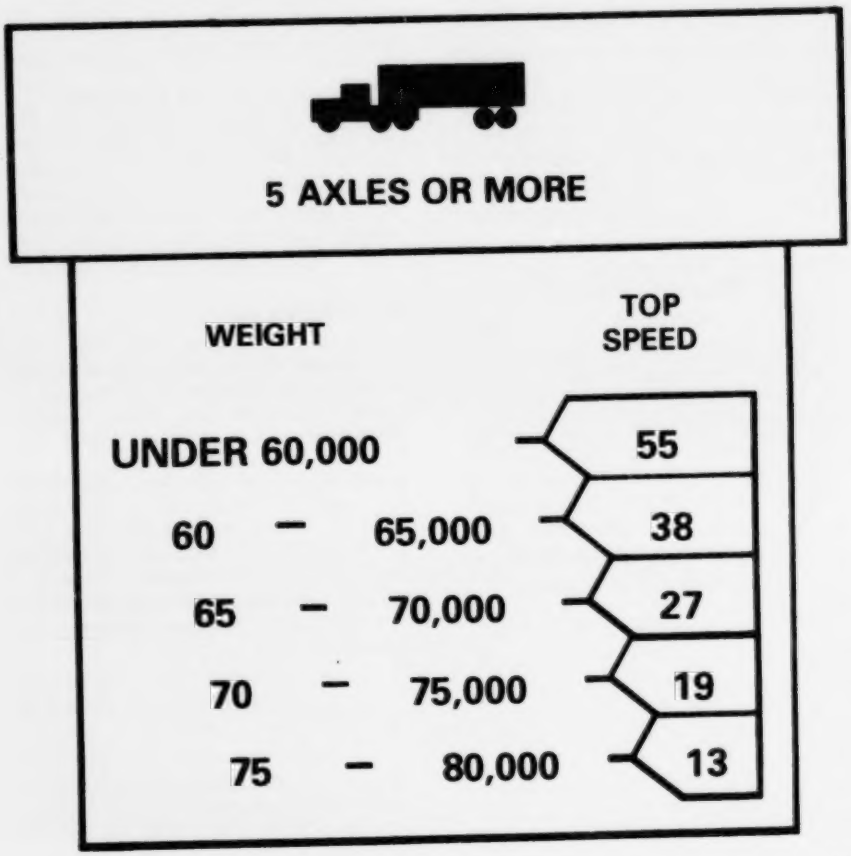
To determine the weight ranges for a weight-specific speed classification, the effects of slight changes in vehicle speed and weight on braking requirements were investigated. This research determined which weight ranges and corresponding speeds would allow the maximum number of trucks to safely descend a grade with a minimum reduction in speed at the lower limit of each weight range.

Additional research indicated a potential problem with combining the grade severity rating with the weight-specific speed signs. For the most severe downgrades—those with a rating of 7, 8, or 9—the severity rating would be different for different weight trucks. For example, for a 36.3 Mg (80,000 lb) truck, a severe downgrade might need to be rated 9; for a 27.2 Mg (60,000 lb) truck, the same downgrade might need to be rated 7. Thus, for safety the same downgrade would have to be assigned two ratings based on truck weight. However, assigning more than one or only one grade severity rating to such a hill could mislead some drivers and create an unsafe driving situation.

Another finding of simulator tests was that the weight-specific speed sign alone allows drivers to select the appropriate gear; therefore, the grade severity rating was unnecessary. As a result, it was determined that weight-specific speed signs were the most effective method for conveying necessary information to truck drivers (fig. 5).

The proposed GSRS consisted of a formula for calculating safe speeds on downgrades by truck weight and the use of weight-

Figure 5.—Weight-specific speed sign.



specific speed signs. The best display format for the weight-specific speed signs will be tested later in the study.

Weight-specific speeds are determined with tolerances built into the calculations to allow for the fact that not all trucks have new brakes and that some trucks operate at less than maximum efficiency because of dust or oil on the brakes.

Conclusions

Although weight-specific speed signs still have to be developed and tested fully, research indicates that the implemented GSRS will improve heavy truck safety on downgrades and also improve traffic flow on hills that have a significant amount of truck traffic.

A set of tables and instructions has been developed that allows safe operating speeds on a specific hill for trucks weighing up to 36.3 Mg (80,000 lb) to be determined quickly. (*6*) The basic formula also is included so safe descent speeds can be calculated for trucks operating with specific use permits that allow gross vehicle weights greater than 36.3 Mg (80,000 lb). Length of grade and degree of slope must be measured accurately if the weight-specific speed calculations are to result in safe operating speeds.

Ongoing Research

Research continues on selecting and simulator testing signs to identify the most effective sign for transmitting weight-specific speed information to truck drivers. After the conclusion of the study, FHWA, with the cooperation of one or more States, expects to field test the GSRS using various methods to gather data on the effectiveness of the system.

- Weight-specific speed signs will be placed at beginnings of downgrades on highways with weigh stations close to the beginning of the downgrade to enable researchers to record speeds at the bottom of the downgrade and match them with the truck's gross vehicle weight.

- Speed readings on a downgrade will be taken before and after installing weight-specific speed signs to determine if the signs impacted the average truck speed at the bottom of the grade.

- Weight-specific speed signs will be installed on hills with frequently used escape ramps. Sign effectiveness will be measured by the change in the use of the ramps. This approach might work best where gravel beds instead of gravity ramps are used for escape ramps. Some trucks can be backed out of a gravity ramp and driven away, making it difficult to accurately assess the number of times the gravity ramp is used. On the other hand, a driver may be able to back out of a gravel arrester bed, but the tire marks in the gravel indicate the escape ramp has been used.

Initial results of the proposed field test probably will not be available before early 1984.

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(*8*) Richard A. Lill, "Development of Grade Severity Rating System," *American Trucking Association*, December 1975.

Paul Abbott, a program analyst in the Environmental Division, FHWA Office of Research, is contract manager for the research study "Evaluation of Techniques to Counteract Truck Accidents on Steep Downgrades." This study is part of FCP Project 1U, "Safety Aspects of Increased Size and Weight of Heavy Vehicles." Mr. Abbott also is contract manager of research studies in the areas of social and economic impact assessment and highway safety.

[2] Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Office of Research, Federal Highway Administration, which includes the Structures and Applied Mechanics Division, Materials Division, Traffic Systems Division, and Environmental Division. The reports are available from the address noted at the end of each description.

Stop, Yield, and No Control at Intersections, Report No. FHWA/RD–81/084

by FHWA Traffic Systems Division

Observations and measurements were made at 140 low-volume intersections (less than 500 vehicles per day on the minor roadway) in Texas, Florida, and New York, three geographically different States. Kind of control—stop, yield, or no control; location—urban or rural; geometry—three-leg or four-leg; major roadway volume; and sight distance were examined to determine their individual and interactive effects on driver behavior, accident experience, and travel time through the intersection. Findings indicated that region, location, and geometry have a negligible effect on safety and traffic operation at low-volume intersections. Yield signs had the lowest road user costs of the three kinds of control considered. Stop signs had the highest user costs.

Limited copies of the report are available from the Traffic Systems Division, HRS–30, Federal Highway Administration, Washington, D.C. 20590.

Methods for Evaluation of Rail-Highway Grade Crossing Improvements, Report No. FHWA/RD–81/114

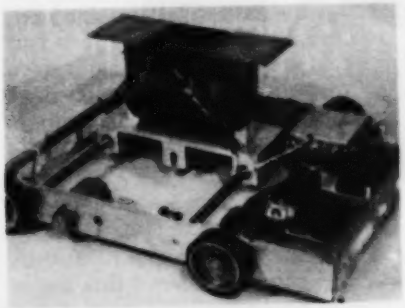
by FHWA Traffic Systems Division

This report discusses the results of a staff study that was performed to identify statistical methods for evaluating rail-highway grade crossing improvements. Six statistical concepts were identified. Three methods provide summaries and graphical displays of data. The other three methods provide tests of significance in comparative studies. National Grade Crossing Inventory and Accident data for 1975–1977 were considered in the study. The methods in the report can be used to compare data for 1975–1977 with data for 1978–1980.

Limited copies of the report are available from the Traffic Systems Division, HRS–31, Federal Highway Administration, Washington, D.C. 20590.

Detection of Flaws in Reinforcing Steel in Prestressed Concrete Bridge Members, Report No. FHWA/RD–81/087

by FHWA Structures and Applied Mechanics Division



In recent years there has been concern that corrosion could be developing in the prestressing steel of inservice prestressed concrete highway bridge members, threatening the structural integrity of the bridges. Currently used inspection procedures rely heavily on visual evidence (rust staining and cracking or spalling of the concrete) that a problem may be developing.

This report describes research to develop a practical nondestructive evaluation (NDE) technique for detecting deterioration in the prestressing steel of prestressed concrete bridge structural members. Fifteen available NDE methods were evaluated, and a magnetic field method was deemed the most promising way of detecting anomalies in ferromagnetic materials embedded in concrete. In this method, a steady-state magnetic field is applied to the prestressed concrete girder being inspected and a magnetic field sensor simultaneously scans stepwise along the length of the girder parallel to each stressing steel element. A perturbance in the scanned field indicates a break or other kind of metal anomaly in the girder. Experiments were conducted on large specimens with simulated steel flaws to determine the influence of a range of conditions and test parameters on the detectability of loss-of-section or fracture. The experiments explored the effects of varying degrees of steel deterioration, presence of adjacent unflawed steel elements, kind of duct, kind of steel, and transverse reinforcing steel configuration.

The magnetic field inspection equipment is installed on a self-propelled, remotely controlled inspection cart that travels along a lightweight track suspended by hangers clamped to the girder being inspected. The hangers are designed to permit an unobstructed scan to be made of the full length of the girder. The inspection hardware attached to the girder weighs approximately 209 kg (460 lb). The magnetic sensor assembly on the inspection cart may be positioned at any transverse location across the width of the girder, and the hangers can be adapted to permit inspection of a variety of prestressed concrete girder shapes.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 241630).

Residual Stress Measurements in Structural Steels, Report No. FHWA/RD–81/086

by FHWA Structures and Applied Mechanics Division

The presence of locked-in residual stresses that can occur in structural steel elements in service has been recognized as a significant design factor only in recent years. In general, residual stresses and working load stresses in steel members add vectorially. It is therefore important to account for residual stresses in design because these stresses can be of significant magnitude.

This report presents the results of a study to develop methodology and instrumentation for nondestructive measurement of residual stresses in structural steel bridge members. An initial state-of-the-art literature survey identified 26 candidate methods for measuring residual stresses, and each was assessed for its applicability to steel bridge components. This screening resulted in the selection of the Barkhausen noise analysis method for measuring surface stresses and

the ultrasonic shear wave birefringence method for measuring average bulk stresses. Although the theory and measurement methodology for both techniques were available before the start of this research study, Barkhausen noise analysis had not been used for field measurements, and ultrasonic birefringence instrumentation suitable for reliable quantitative measurements of residual stresses had not been developed. Because the methods complement one another, two experimental instrumentation systems were assembled and laboratory experiments were conducted to develop the potential of each method for field measurement of residual stresses in steel eyebar heads, girders with cover plates, and high-strength bolts. The success of these preliminary feasibility tests led to the development of prototype portable field instrumentation systems.

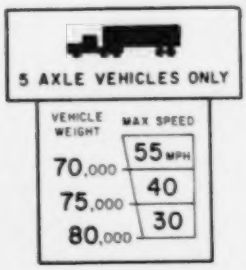
Subsequent field evaluations showed that the two new instrumentation systems could provide repeatable and reliable field data from which comprehensive analyses of residual stresses in steel elements of highway bridges could be made. The instrumentation

can be used to obtain measurements in the structural steel fabrication shop, on the bridge during erection, or on existing bridges. Only nominal surface preparation of the structural member is required for making the measurements.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 241499).

The Development and Evaluation of a Prototype Grade Severity Rating System, Report No. FHWA/RD–81/185

by FHWA Environmental Division



This report presents a model for calculating downgrade severity and the maximum safe descent speed for a truck of a given weight and presents a prototype sign for conveying the weight-specific speed information to drivers. The method used to calculate the maximum safe descent speed considers length and degree of slope, vehicle weight, beginning brake temperature, and engine braking capacity. The data used to calculate the recommended descent speeds were collected through computer simulation and in road tests using an instrumented test truck. The recommended descent speed is calculated to allow the driver to negotiate the downgrade without overheating the vehicle brakes and to stop at the bottom of the grade or at any point on the grade.

Testing results indicate the best sign configuration displays vehicle weight by categories on the left and recommended speed on the right. Only vehicle weight and recommended speed are included on the sign because simulator testing results indicated that truck drivers downshift to an appropriate gear when given a specific speed to drive.

Limited copies of the report are available from the Environmental Division, HRS–43, Federal Highway Administration, Washington, D.C. 20590.

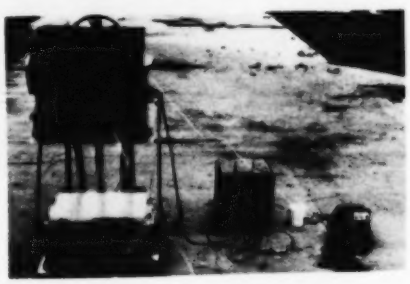
Rapid Determination of the Chloride Permeability of Concrete, Report No. FHWA/RD–81/119

by FHWA Materials Division

Techniques have been developed for rapidly determining the permeability of various concretes to chloride ions. The most promising method involves applying a 60 to 80 d.c. voltage for 6 hours to either a section of a reinforced concrete bridge deck or to a core taken from a concrete structure. Both variations require conditioning of the specimen before the test to eliminate test anomalies caused by low sample moisture contents.

One core specimen per day can be tested, and a complete test, including conditioning, takes 2 days. The field apparatus can conduct four tests in 5 days on a given bridge deck. Results have correlated well with FHWA 90-day ponding data on companion specimens. Concretes can be ranked according to high, moderate, low, or very low chloride permeability. Further work is needed to make the test more applicable to field testing of bridge deck overlays.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 140724).



Usage Guide for Rapid-Set Epoxy Adhesive (118-AF) for Traffic Markers, Report No. FHWA/RD–80/032

by FHWA Materials Division

This report describes a new rapid-set, two-component epoxy adhesive for bonding traffic markers to roadway surfaces and provides guidance for its purchase. This adhesive is designed for machine mixing and dispensing and has the following principal features: Polymercaptan cure, which imparts rapid set at low temperatures; fibrillated polyethylene as the thixotrope (nonasbestos); and low viscosity, which allows good mixing even at moderately low temperatures. The rapid-set adhesive enables traffic to pass over the markers in less than 15 minutes after being placed at temperatures of 22° to 28° C (72° to 82° F).

This guide is designed to provide users and purchasers detailed information on the background of the development of the adhesive; composition of the adhesive; properties and experience in the field, including comparisons with the California Rapid-Set Epoxy Adhesive; use of the adhesive in the field and hauling precautions; and raw material costs. A proposed specification is presented.

Limited copies of the report are available from the Materials Division, HRS–23, Federal Highway Administration, Washington, D.C. 20590.

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items that have been recently completed by State and Federal highway units in cooperation with the Implementation Division, Office of Development, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies.

U.S. Department of Transportation
Federal Highway Administration
Office of Development
Implementation Division
(HDV–20)
Washington, D.C. 20590

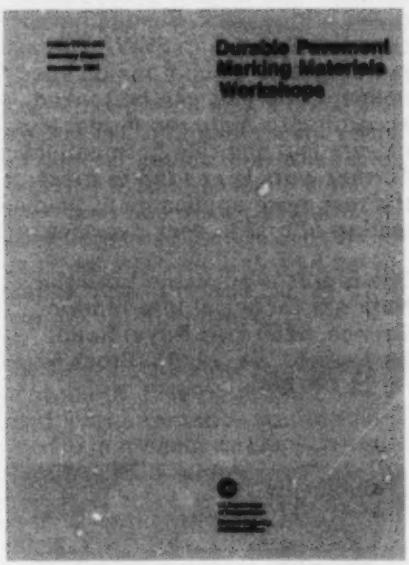
Items available from the Implementation Division can be obtained by including a self-addressed mailing label with the request.

Durable Pavement Marking Materials Workshops, Report No. FHWA–TS–81–221

by FHWA Implementation Division

This report summarizes information presented at five workshops held in 1981 on the evaluation of six durable pavement marking materials. The workshops included presentations on paints, thermoplastics, epoxies, polyesters, preformed materials, and epoxy thermoplastic. The primary objective was to present the most current information on pavement marking materials. The characteristics, application techniques, and performance of each material are discussed and the advantages, disadvantages, and costs are summarized. The information presented at the five workshops was based on field testing of the materials in several States.

This report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 140260).



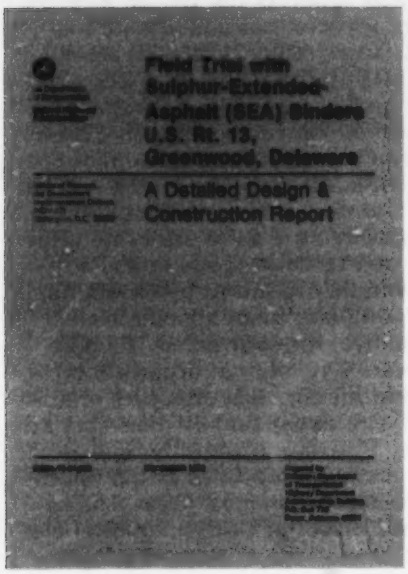
Field Trial with Sulfur-Extended-Asphalt (SEA) Binders, U.S. Rt. 13, Greenwood, Delaware, Report No. FHWA–TS–81–203

by FHWA Implementation Division

This report is part of a series of reports that describe the procedures and testing used to design and construct pavement overlays with SEA binders for comparison against overlays with conventional asphalt binders. SEA pavement field trials in Minnesota, Washington, and Mississippi will be evaluated in future reports.

This report describes the materials, equipment, and quality control procedures used to construct the SEA pavement sections and highlights the design procedures and emissions control monitoring used. The performance of pavement overlays whose SEA binders are formulated with an "in-line blender" before introduction into the pugmill are compared with overlays whose SEA binders are formulated by mixing sulfur and asphalt in the pugmill. The report indicates that pugmill mixing of sulfur and asphalt is sufficient to insure satisfactory blending.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 131814).

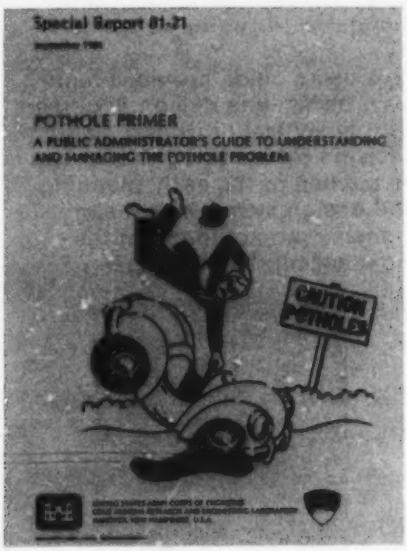

Field Trial with Sulphur-Extended Asphalt (SEA) Binders U.S. Rt. 13, Greenwood, Delaware
A Detailed Design & Construction Report

Pothole Primer, Special Report No. 81–21

by the Cold Regions Research and Engineering Laboratory

This report was prepared to help elected city, town, and county officials understand and manage their pothole problems in asphalt pavements. In addition to these public administrators, the report should be of interest to city and county engineers in establishing a pothole repair program. Because the report is intended as a primer, it only highlights the major causes of and general solutions to the pothole problem.

Limited copies of the report are available from the Implementation Division.


Special Report 81-21
POTHOLE PRIMER
A PUBLIC ADMINISTRATOR'S GUIDE TO UNDERSTANDING AND MANAGING THE POTHOLE PROBLEM
CAUTION POTHOLES

Post Construction Evaluation of U.S. 69 Sulfur-Extended-Asphalt (SEA) Pavement Test Sections in Lufkin, Texas, Report No. FHWA–TS–80–235

by FHWA Implementation Division

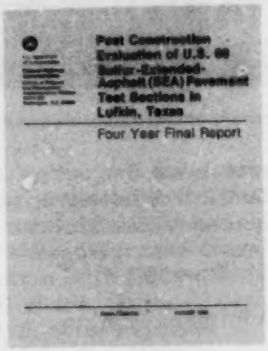
This report presents a post construction evaluation of an experimental SEA pavement field trial on U.S. 69 north of Lufkin, Tex. It also describes the materials, equipment, and quality control procedures used during construction.

The binders used in this field trial consist of pure asphalt cement for the control sections and a 30/70 weight percent blend of sulfur and asphalt cement for the SEA test binder. All elements of the structural design, including thickness, were produced in pairs for comparison of SEA sections with asphalt sections. The thickness designs used in the test sections were the same as those specified by the Texas State Department of Highways and Public Transportation for the conventional sections of this highway. Two thinner sections with SEA binders were constructed to see if distress would appear in 2 to 3 years.

Because of the excellent performance of the SEA pavement sections to date, the evaluation program was extended, and a final

field evaluation report will be published and distributed at the end of the extended evaluation period in 1983.

Limited copies of the report are available from the Implementation Division.


Post Construction Evaluation of U.S. 69 Buton-Extended-Asphalt (BEA) Pavement Test Sections in Lufkin, Texas
Four Year Final Report

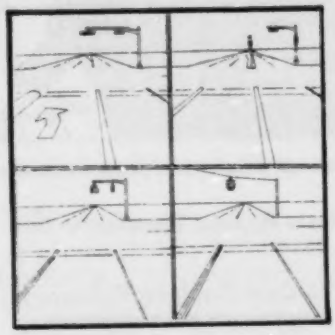
Guidelines for Signalized Left Turn Treatments, Implementation Package 81–4

by FHWA Implementation Division

This report presents easy-to-use guidelines for selecting the best left turn treatment to use at a signalized intersection. The information contained in this report is based on a synthesis of current research and the operational experiences of over 200 practicing traffic engineers.

The guidelines will be useful for traffic engineers considering left turn phasing at an intersection. The advantages and disadvantages of numerous phasing schemes are discussed as are signal displays for left turn phasing. Attention is given to highway capacity, fuel consumption, and safety trade-offs of the various kinds of left turn treatments. Also presented is a specific set of guidelines for daily use by traffic engineers.

The report may be purchased for $3 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00243–4).



Planning and Scheduling Work Zone Traffic Control, Implementation Package 81–6

by FHWA Implementation Division

Traffic control problems arise whenever traffic must be moved through or around highway construction, maintenance, or utility work sites. Because emphasis in the next decade will be on reconstruction and maintenance activities instead of new construction, higher traffic volumes will be affected. Effective work zone traffic control must be planned carefully, applied systematically, and maintained continuously.

This users guide provides highway, traffic, and design engineers with analytical procedures and decision methodologies that can be applied in the early planning and design stages of a major highway project to select the most appropriate and cost-effective traffic control strategy to be implemented. The guide is intended for planning long term, stationary work zones, not for moving or short term work zones.

The user guide may be purchased for $4.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00235–3).

UTCS Functional Description—Enhanced First Generation Software, Report No. FHWA–TS–79–228

by FHWA Implementation Division

This report is the first in a series of reports that documents the Urban Traffic Control System (UTCS) Enhanced First Generation Software for computer-based traffic control systems in States and municipalities throughout the United States. The report will aid potential users and suppliers in specifying a software system tailored to their needs as the software is organized by functional module to meet specific traffic control requirements. The software's functional organization and hierarchical structure enable future expansion or modification by inserting or modifying specific functional modules at the appropriate hierarchical level. The report describes the functional elements of the enhanced software and the minimum hardware and operating system program requirements necessary to implement the software.

Final acceptance testing of the software is scheduled for November 1982 after the software has been installed in Birmingham, Ala. This pilot city installation is expected to demonstrate software portability and its ability to control at least 250 intersections.

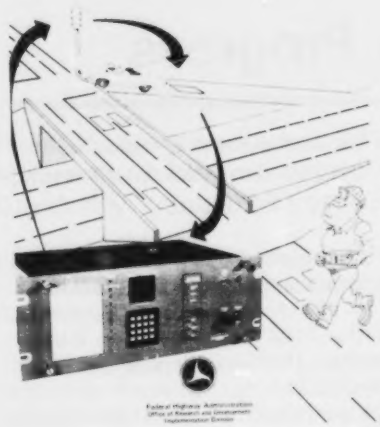
Limited copies of the report are available from the Implementation Division.

Type 170 Traffic Signal Controller System Reports

by FHWA Implementation Division

The California, New York, Oregon, and Kentucky Departments of Transportation are pursuing a unique approach to acquiring microcomputer-based intersection controllers. Rather than purchasing traditionally available controller equipment from traffic signal manufacturers, these States are purchasing and installing general purpose microcomputers according to their own jointly developed specifications. California and New York also are collaborating on the development of software and acceptance test procedures. These unique controllers are known as Type 170's, and currently there are over 1,500 in service in these four States. New York and California state that the advantages are reduced purchase cost, improved flexibility, and expediency.

The controllers currently are manufactured by several companies and low bid purchasing is possible. Because 170 controllers manufactured by different companies are interchangeable, it is possible to replace malfunctioning controllers with a spare microcomputer-based controller.



Local Intersection Program, Report No. FHWA–IP–79–10, is intended for traffic signal planning and operations. The manual presents operational features, general information on the control program, narrative description of program routines, and a program listing. The local intersection control program is designed to accommodate most typical intersection control strategies. It can function in semiactuated, fully actuated, or volume-density modes.

Diamond Interchange Program Users Manual, Report No. FHWA–IP–80–4, presents operational features and general information on the diamond interchange control program.
Diamond Interchange Program Software Documentation, Report No. FHWA–IP–80–5, presents program routines, flow charts, and a program listing.

The diamond interchange program can accommodate three diamond interchange strategies and function in three modes. Time of day and traffic conditions are used to select between modes of control.

Report No. FHWA–IP–79–10 may be purchased for $6, Report No. FHWA–IP–80–4 may be purchased for $5, and Report No. FHWA–IP–80–5 may be purchased for $6.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock Nos. 050–001–00168–3, 050–001–00224–8, and 050–001–00225–6).

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. Space limitation precludes publishing a complete list. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R)—Performing State Highway or Transportation Department; National Cooperative Highway Research Program (NCHRP)— Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety

Title: Reevaluation of Traffic Control at Nonsignalized Intersections. (FCP No. 41A1974)
Objective: Evaluate use of yield, two-way stop, and four-way stop control at intersections with emphasis on the effects of less restrictive control on intersection safety.
Performing Organization: University of Maryland, College Park, Md. 20742
Expected Completion Date: October 1982
Estimated Cost: $31,000 (HP&R)

FCP Category 2—Reduce Congestion and Improve Energy Efficiency

FCP Project 2J: Practicality of Automated Highway Systems

Title: FHWA Program on Automated Highway Systems. (FCP No. 22J1104)
Objective: Document the FHWA program on the automated highway system including its objectives, scope, approaches used to reach project objectives, major accomplishments, and recommended future activities.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: September 1982
Estimated Cost: $30,000 (FHWA Staff Research)

FCP Project 2L: Detection and Communications for Traffic Systems

Title: Field Hardware Problems With Traffic Control Devices. (FCP No. 22L1092)
Objective: Investigate field reliability and operational performance problems with active, electronics-based, traffic control devices.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: January 1983
Estimated Cost: $9,000 (FHWA Staff Research)

Title: Assessment of Data Communications for Traffic Control. (FCP No. 22L2102)
Objective: Survey current practices, trends, problems, and costs associated with data communications for traffic control.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: December 1982
Estimated Cost: $11,000 (FHWA Staff Research)

Title: Artificial Speech for Highway Advisory Radio. (FCP No. 22L2122)
Objective: Investigate the state of the art of speech synthesis technology and provide a technological assessment of its use in audio signing applications.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: September 1983
Estimated Cost: $26,000 (FHWA Staff Research)

Title: Assessment of Status, Trends, and Needs in Motorist Aid Communications. (FCP No. 22L3012)
Objective: Update the status, trends, and needs in motorist aid communications since definitive contractual effort of 1975–1976.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: December 1982
Estimated Cost: $11,000 (FHWA Staff Research)

FCP Project 2N: Improved Traffic Signing and Motorist Information Systems

Title: Evaluation of Variable Aspect Sign. (FCP No. 22N1102)
Objective: Assess the effectiveness of the variable aspect sign in terms of improving the conspicuity of warning and regulatory displays.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: December 1982
Estimated Cost: $17,000 (FHWA Staff Research)

Title: Nonilluminated Opaque Background Guide Signs. (FCP No. 22N2092)
Objective: Determine whether overhead guide signs should be permitted to have nonreflectorized backgrounds and whether it is important for the driver to view the green sign background at night.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: October 1983
Estimated Cost: $18,000 (FHWA Staff Research)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4D: Remedial Treatment of Soil Materials for Earth Structures and Foundations

Title: Design of Laterally Loaded Drilled-In Piers for Landslide Correction Anchored in Sedimentary Rocks. (FCP No. 44D5212)
Objective: Develop design procedure for laterally loaded piers used in landslide corrections. Write computer program to increase efficiency and capability for slope stability analyses of drilled-in piers supporting slopes or retaining structures. Develop users manual for the computer program.
Performing Organization: Purdue University, West Lafayette, Ind. 47907
Funding Agency: Indiana Department of Highways
Expected Completion Date: December 1983
Estimated Cost: $51,000 (HP&R)

FCP Project 4K: Cost Effective Rigid Concrete Construction and Rehabilitation in Adverse Environments

Title: New Systems for Delamination Rebonding Prior to Cathodic Protection. (FCP No. 34K2102)
Objective: Develop a material that can be injected, can rebond delamination areas of bridge decks, and is conductive when moist to allow the uniform passage of cathodic protection current through the rebonded area.
Performing Organization: Pandalai Coating Company, Brackenridge, Pa. 15014
Expected Completion Date: September 1982
Estimated Cost: $111,000 (FHWA Administrative Contract)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5L: Safe Life Design for Bridges

Title: Evaluation and Modification of Weigh-In-Motion System. (FCP No. 45L3172)
Objective: Evaluate weigh-in-motion system and implement one in Pennsylvania.
Performing Organization: Bridge Weighing Systems, Warrensville Heights, Ohio 44128
Funding Agency: Ohio Department of Transportation
Expected Completion Date: November 1983
Estimated Cost: $145,000 (HP&R)

FCP Category 0—Other New Studies

Title: Comparison of Conventional Field and Photogrammetric Cross Sections. (FCP No. 40M4133)
Objective: Determine if cross sections obtained from mapping photography (before clearing and grubbing) are accurate enough to be used as original cross section for pay quantities.
Performing Organization: Office of Location, Forest Park, Ga. 30050
Funding Agency: Georgia Department of Transportation
Expected Completion Date: September 1982
Estimated Cost: $9,000 (HP&R)

New Publications

Highway Statistics 1980, a 167-page book, the 36th in the annual series, presents statistical and analytical tables of general interest on motor fuel, motor vehicles, driver licensing, highway user taxation, State and local highway financing, road and street mileage, Federal-aid for highways, and highway usage and performance. Also reported are 1979 highway finance data for municipalities, counties, townships, and other units of local government. A listing of the data is given in the table of contents, and a brief discussion is given in the text accompanying each section.

The publication may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00236–1). It is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Report No. FHWA–HP–HS–80) in microfiche and paper copy.

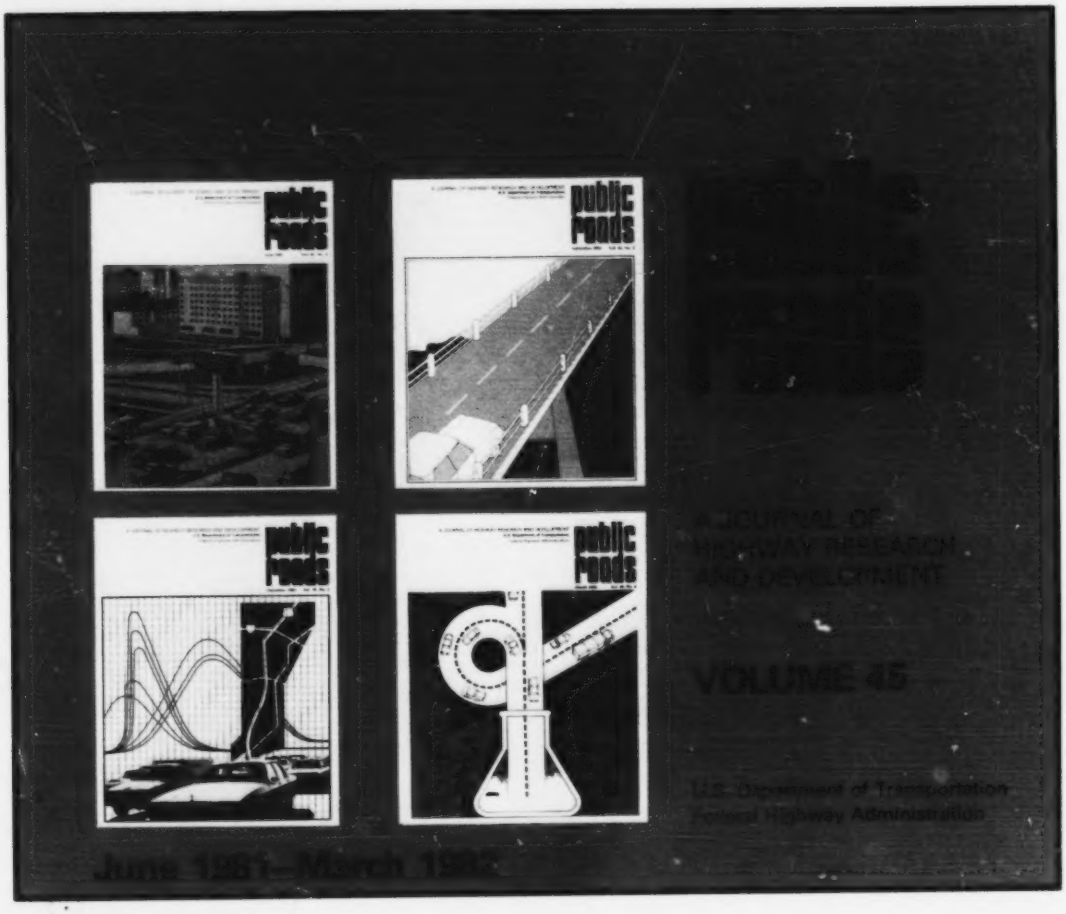
The Highway Statistics series has been published annually since 1945, but the earlier editions, except 1974–1979, are now out of print. Much of the earlier data is summarized in **Highway Statistics, Summary to 1975.** These documents also may be purchased from GPO or NTIS.

Selected Highway Statistics and Charts, 1980 is a 30-page compilation of statistical highlights and charts prepared as a convenient summary supplement to various tables published in **Highway Statistics 1980** and prior years. Historical trends, as well as 1981 estimates, are included. Copies may be obtained from the Office of Public Affairs or the Highway Statistics Division, HHP–41, Federal Highway Administration, Washington, D.C. 20590.

Beginning with this issue, vol. 46, No. 1, June 1982, *Public Roads* has a new logo and is reduced in size. In accordance with the 1981 *Graphics Standards for the U.S. Department of Transportation* manual, the magazine is now 8 ½ × 11 inches and the title is now in upper and lower case TransBold type. These changes comply with an effort to create a uniform visual communications system and establish overall identity with the Department.

☆U.S. Government Printing Office: 1982—341–783/104

TITLE SHEET, VOLUME 45



The title sheet for volume 45, June 1981–March 1982, of *Public Roads, A Journal of Highway Research and Development*, is now available. This sheet contains a chronological list of article titles and an alphabetical list of authors' names. Copies of this title sheet can be obtained by sending a request to the editor of *Public Roads*, U.S. Department of Transportation, Federal Highway Administration, HDV–14, Washington, D.C. 20590.

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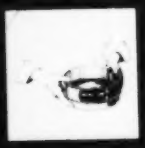
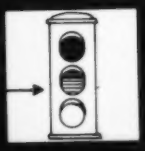
in this issue

Scour at Culvert Outlets in a Sandy-Clay Material

Reduction of Truck-Induced Splash and Spray



Aggregate Gradation Control: Part I—An Analysis of Current Aggregate Gradation Control Programs



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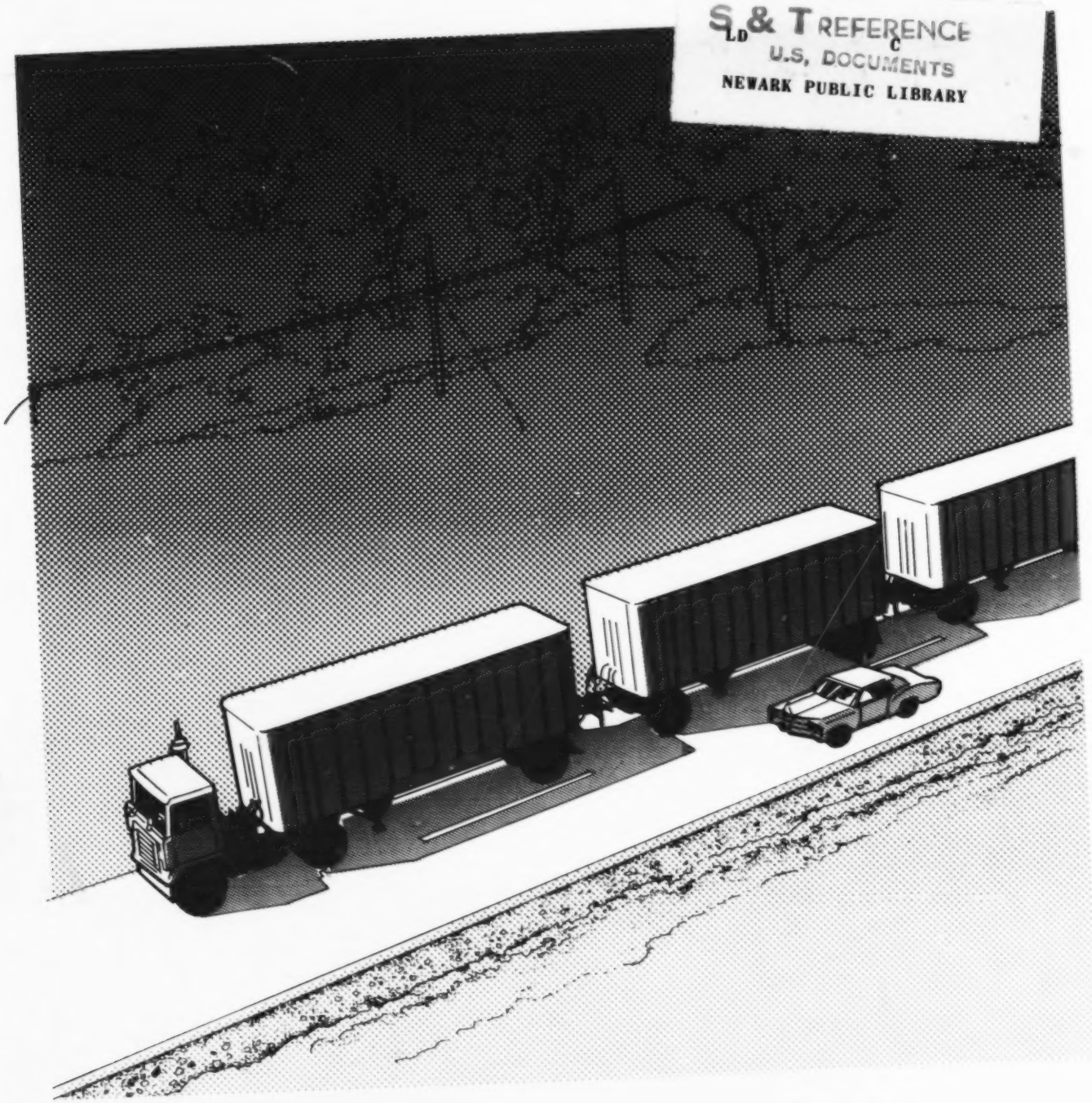

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Public Roads, A Journal of Highway Research and Development, is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, at $9.50 per year ($2.40 additional for foreign mailing) or $3.25 per single copy (85¢ additional for foreign mailing). Subscriptions are available for 1-year periods. Free distribution is limited to public officials actually engaged in planning and constructing highways and to instructors of highway engineering.

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Reorganization of the Federal Highway Administration's Offices of Research and Development

In July 1982 the Federal Highway Administration (FHWA) Offices of Research and Development were reorganized and renamed the Offices of Research, Development, and Technology (RD&T). The purpose of the reorganization was to reflect changing programs and priorities and emphasize the importance of the technology transfer process, improve management communications and operations, and accommodate necessary personnel reductions.

Major features of the new organization, shown in the chart below, include the following:

- The National Highway Institute (NHI) was transferred intact from the staff of the Federal Highway Administrator to the Associate Administrator for RD&T because of the close relationship between NHI's and RD&T's missions, especially in technology transfer functions. The change also allows a more efficient sharing of personnel and administrative operations.

- A Science Advisor position was established. The incumbent advises and assists the Associate Administrator on technical issues and represents FHWA in various national and international scientific activities.

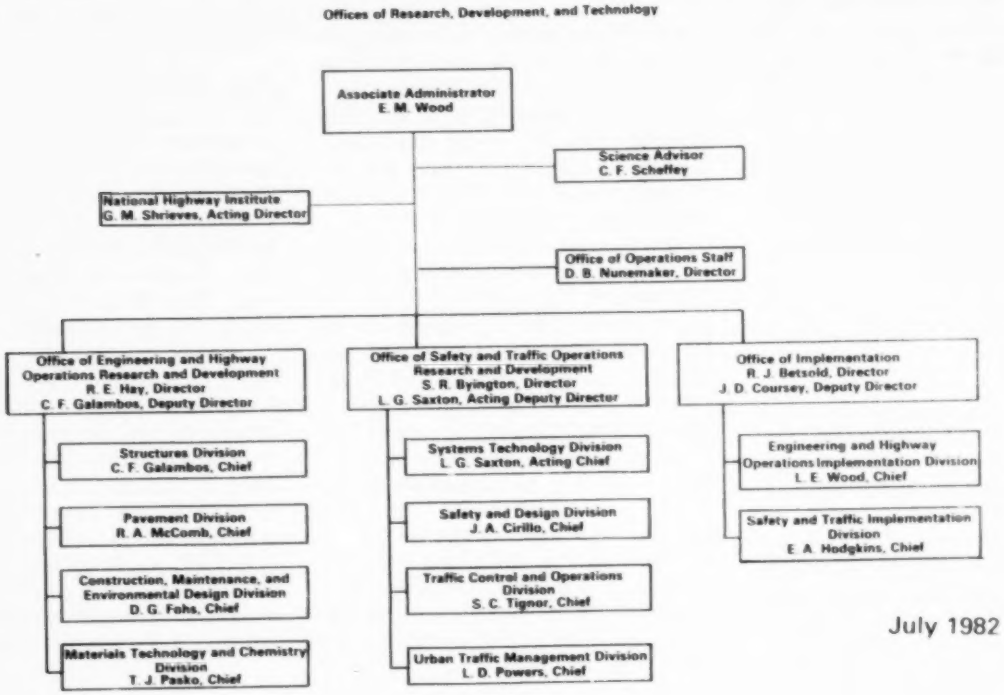
- An Office of Operations Staff was created and includes budget, program analysis, personnel, publications, and related functions.

- Three major offices were created—Office of Engineering and Highway Operations Research and Development (structures, materials, and hydraulics), Office of Safety and Traffic Operations Research and Development (operational safety, traffic engineering, and supporting systems and technology), and Office of Implementation (technology transfer and related coordination). The remaining line staff were organized into 10 divisions that are functionally alined to better parallel the programs and organizational structure of the other FHWA operating offices.

- Management levels below the division level, such as groups, were eliminated.

- The mechanical, electronics, computer, and publication functions previously under one division were reassigned as follows:

  Mechanical—Materials Technology and Chemistry Division,
  Electronics—Systems Technology Division,
  Computer—Safety and Traffic Implementation Division, and
  Publications—Office of Operations Staff.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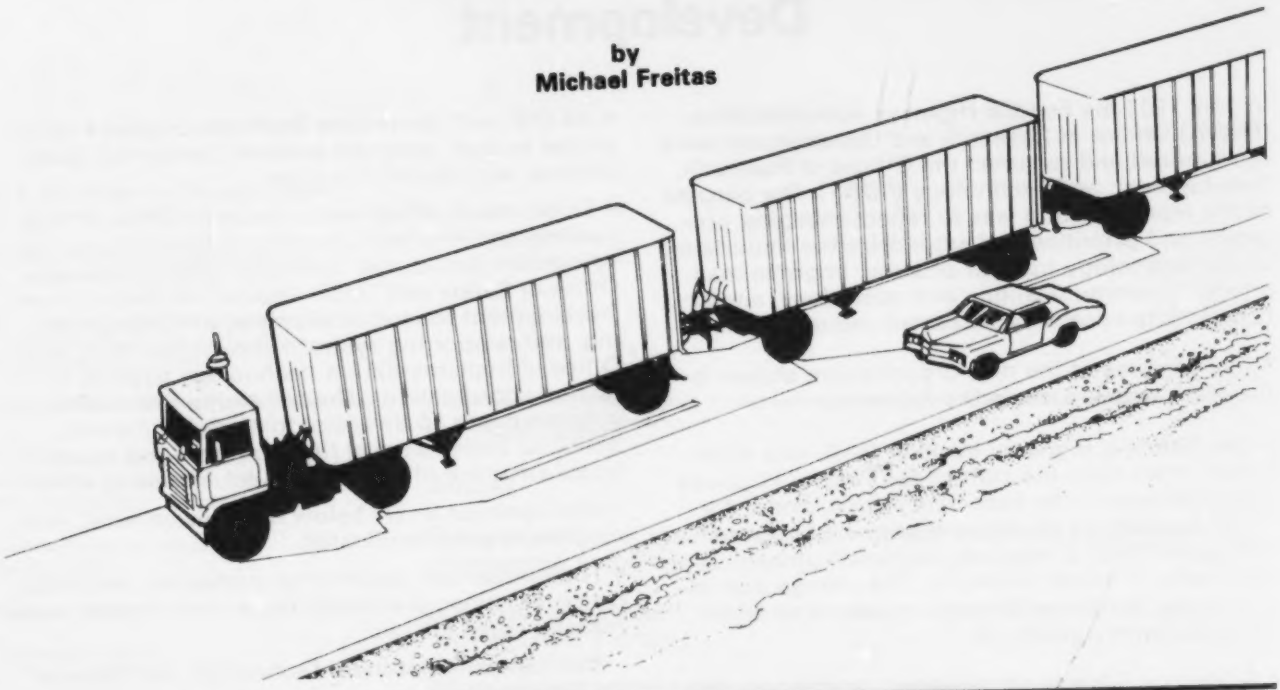
July 1982

A Review of Accident Research Involving Truck Size and Weight

by
Michael Freitas



The most obvious method of determining how various highway, driver, and vehicle factors contribute to highway accidents is by collecting and analyzing accident data. This method has been used in several studies, including a Federal Highway Administration (FHWA) study completed in 1980, to determine the effect of increased truck size and weight on accident experience. A review of these studies is necessary, however, to resolve conflicting study results and put them into proper perspective.

Accident Research Terminology

One source of confusion in accident research is the terminology used. Without an understanding of similar terms such as accidents, accident rates, involvements, fatalities per accident, and injury rates, it is difficult to understand study results and thus compare results from different studies. For example, a simple definition of a motor vehicle accident might be any collision of a motor vehicle and some other object or vehicle with enough force to damage the motor vehicle(s) or the object struck or to injure occupants of the motor vehicle(s) involved. Most States set minimum reporting criteria for accidents. Accidents involving a fatality are always reported. Most nonfatal injury accidents are reported, although in some cases the severity of the injury establishes the reporting criteria. Property-damage-only (PDO) accidents do not have to be reported if the damage is under a prescribed dollar value. This value ranges from $100 in some States to $2,000 for FHWA's Bureau of Motor Carrier Safety (BMCS) truck accident file. Thus, any accident study uses only a sample of all accidents.

Another key term is accident involvement. If a car and a truck collide, is it a car accident or a truck accident? When comparing the relative safety of various vehicle types, this distinction is important. When comparing the accident experience of cars versus trucks or trucks of various configurations, it is appropriate to use involvements in accidents. Thus, an accident involving three vehicles would be counted as three involvements.

Neither the number of accidents nor involvements alone is an appropriate measure for most safety comparisons because neither measure accounts for risk. For example, 80-year-old drivers may have fewer accidents in a year than 30-year-old drivers; however, this does not mean that older drivers are better drivers. There are fewer 80-year-old drivers and typically they drive fewer kilometres (miles) each year; thus, one would expect them to have fewer total accidents in a year. To compare these two groups properly, exposure, the relative risk or opportunity for an accident, must be taken into account. Exposure, a term that has drawn considerable attention recently, is a necessary element for

comparing accident experience. Commonly used exposure measures are number of vehicles, vehicle-kilometres (vehicle-miles) of travel, cargo kilogram-kilometres (ton-miles) of travel, and passenger-kilometres (passenger-miles) of travel. It is essential to select the proper exposure measure for a specific safety assessment.

Exposure is used to calculate accident and involvement rates. Accident rate is the number of accidents divided by the exposure measure. Involvement rate is the number of accident involvements divided by the exposure measure. These rates can be compared to determine the relative safety of various vehicles, highway sections, and drivers.

Appropriate measures for severity comparisons might be injuries or fatalities per accident. However, these variables do not measure the probability of an accident, but only the probability of an injury or fatality given an accident occurs. The variables are very useful for evaluating the crashworthiness of vehicles or the performance of roadside barriers.

The incidence of severe accidents is measured by fatality rates, fatal accident rates, injury rates, and injury accident rates. Injury rate is the total number of injuries divided by the appropriate exposure measure. Fatality rate is the total number of fatalities divided by exposure. Injury accident rate and fatal accident rate, however, are the total number of accidents in which an injury or fatality occurred, respectively, divided by exposure.

Key Accident Research Studies

Following is a review of 10 key accident studies relating to increased truck size and weight. In general, the trucks involved were large—not small vans, panels, or pickups—and included single-unit trucks with at least six tires and gross weights of more than 4.5 Mg (10,000 lb) empty and 9.1 Mg (20,000 lb) loaded and all combination trucks (singles [tractor-semitrailer], doubles [tractor-semitrailer-full trailer], and triples [tractor-semitrailer-two full trailers]).

Some of the following studies cited were part of general economic reviews of increased truck size and weight that used available accident data for a safety assessment. Others are general truck accident studies in which the major issue was truck safety; hence, size and weight were just two of many variables examined for their safety effect. Finally, some studies were specifically designed to assess the effect of increased truck size and weight on accidents.

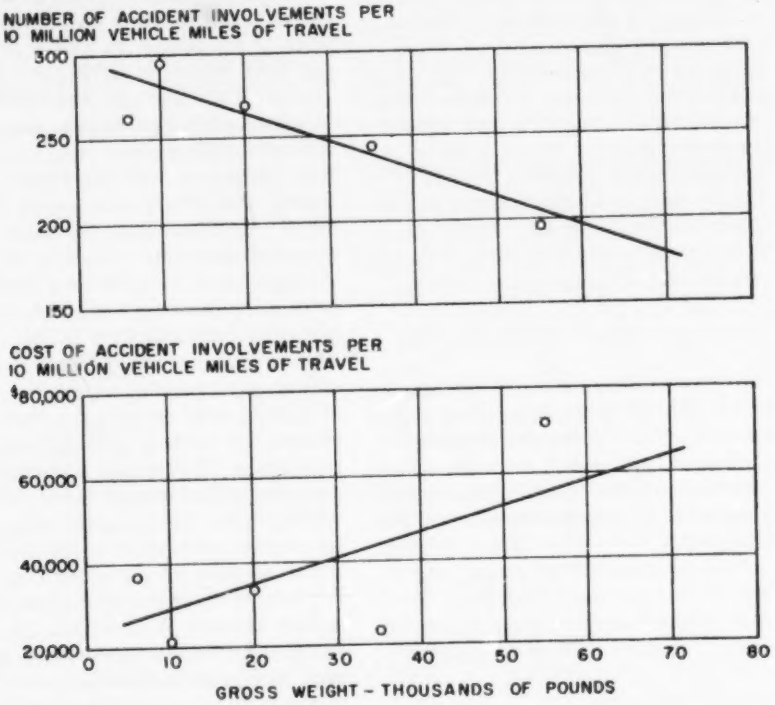
General size and weight studies

In 1964 the Secretary of the U.S. Department of Commerce submitted to Congress an economic assessment of increased truck size and weight that included a chapter on safety. (*1*)[1] Included in that chapter was an analysis of truck accidents by gross weight. The analysis indicated that the accident involvement rate of trucks decreased as weight increased. An analysis of accident costs, however, indicated that the cost of accidents increased with increasing weight (fig. 1).

Unfortunately, only registered weight was available for the analysis. No data were available on actual weight. Because there is little relationship between registered weight and actual weight, this analysis did not address the critical issue of the effect of loading on the accident experience of large trucks. The registered weights of most tractor-trailer combinations are similar, but their actual weights can vary by more than 22.7 Mg (50,000 lb).

Because all truck types with registered weights from less than 4.5 Mg (10,000 lb) to greater than

Figure 1.—Gross vehicle weight of trucks related to the number and cost of accident involvements in Illinois, 1958. (1)



1 mile = 1.61 km

1,000 lb = 0.45 Mg

[1] Italic numbers in parentheses identify references on page 52.

31.8 Mg (70,000 lb) were included in the analysis, the data did not necessarily indicate the effect of weight. To examine the effect of weight on accident experience, it would be necessary to control for truck type. Because all trucks were included in this analysis, the data more likely indicated the effect of truck type rather than weight. Additionally, because the analysis included a range of truck types with various kinds of usage, it was simultaneously an analysis of road type because large combination trucks tend to travel on rural, high-design highways, while smaller, single-unit trucks tend to travel on urban highways, including city streets.

Such variance in usage would explain the apparent discrepancy between accident involvements and accident costs previously noted. The lighter or smaller trucks primarily travel on roads with a high incidence of accidents; the larger trucks travel primarily on roads with a low incidence of accidents. However, accidents tend to be less costly on urban roads and on roads without controlled access because of lower travel speeds.

A classic study on the economics of increased truck size and weight also discussed safety. (*2*) The only data available for study came from turnpikes on which the "turnpike double" was allowed to operate and from a test operation of "turnpike doubles" and "triples" conducted by the State of Idaho. The "turnpike double" is a tractor pulling two 12.2 to 13.7 m (40 to 45 ft) trailers. The "triple" is a tractor pulling three 8.2 m (27 ft) trailers. Both of these vehicles are approximately 30.5 m (100 ft) long and should not be confused with the more common "western double," which is a tractor pulling two 8.2 m (27 ft) trailers and is usually 19.8 m (65 ft) long. The analysis of the Idaho and turnpike data indicated that these very long and heavy combination trucks had good safety records. For example, one carrier reported his turnpike doubles experienced one accident per 2 400 000 trailer-km, or 1 200 000 vehicle-km (1,500,000 trailer-miles, or 750,000 vehicle-miles). This compared with an accident frequency for all trucks of one accident per 435 000 km (270,000 miles). The difficulty in generalizing from the turnpike and Idaho test data is that the very long and heavy combination trucks involved do not necessarily represent typical truck operations. Such combinations usually are operated under special permit or special regulations to insure their safe operation. Only modern, well-maintained equipment is used, and operators usually are experienced drivers with excellent driving records. Also, these combination trucks travel almost exclusively on high-design facilities with controlled access.

In 1969, FHWA examined the accident experience of both "western doubles" and "turnpike doubles."[2] The "western doubles" information was provided by two major interstate carrier firms. Involvement rates for both singles and doubles operated by these two firms were computed and compared. In all cases the doubles had a lower accident involvement rate than the singles. Unfortunately, no effort was made to compare singles and doubles in only those States where both operate. Without such a control, this comparison was, to some extent, a comparison of States where doubles were allowed versus States where doubles were not allowed. Also, it should be noted that the data were provided by two of the largest motor carrier firms in the United States, both having excellent safety records.

The "turnpike doubles" comparison suffered from the same problem as other "turnpike doubles" analyses because it compared the accident involvement rate of doubles with all other vehicles on the New York Thruway. The analysis indicated that the doubles had a lower involvement rate than the rest of the traffic stream (table 1). Again, these "turnpike doubles" operated under a special set of restrictions designed to enhance their operational safety.

[2] "Review of the Safety and Economic Aspects of Increased Vehicle Sizes and Weights," unpublished report, *Federal Highway Administration,* Washington, D.C., September 1969.

General truck accident studies

In 1971 a statistical analysis of truck accident involvements was conducted using accident data from several States and from the BMCS accident file. (*3*) Accident and matching exposure data also were obtained from three turnpikes. The turnpike data, primarily the data from the Indiana Turnpike, provided additional insight into the issue of truck size. The accident involvement rates of singles and doubles on the Indiana Turnpike were computed, and, as shown in previous studies, the doubles (12.2 m [40 ft] long) had lower involvement rates than the singles. Again, the operation of these doubles is tightly controlled on the Indiana Turnpike to insure safe operation.

In this same study, the accident severity of singles and doubles also was compared using BMCS accident data. Casualty rates (the number of people killed or injured per accident) were calculated for both truck types. In every comparison, doubles had more injuries or fatalities per accident than singles, although there were significant differences only in the injury category, not the fatality category. No effort was made to separate these data by road type or rural or urban location. Although both singles and doubles primarily are line haul vehicles, generally doubles travel almost exclusively on rural freeways and other rural primaries while singles travel more on urban routes for pickup and delivery purposes. Therefore, the doubles' severity rates would tend to be higher than the singles' rates because, in general, accidents are more severe on rural high-speed highways than on low-speed urban streets. A comparison of accident involvement rates, which was not possible because of insufficient exposure data, might have favored doubles because rural freeways and other rural primaries generally have the lowest involvement rates.

Table 1.—Accident involvements of "oversized" doubles on the New York Thruway compared with involvements of all vehicles using the Thruway[1]

Year	Vehicle involvements		Vehicle-miles operated		Involvement rate per 1 million vehicle-miles	
	Doubles	All vehicles[2]	Doubles	All vehicles	Doubles	All vehicles
			Thousands			
1963	19	7,012	10,972	2,767,338	1.7	2.5
1964	19	7,324	13,400	3,005,818	1.4	2.4
1965	28	7,826	16,501	3,227,595	1.7	2.4
1966	27	8,013	18,313	3,378,501	1.5	2.4
1967	33	8,439	20,397	3,533,673	1.6	2.4
1968	52	8,804	26,890	3,728,089	1.9	2.4
6-year total	178	47,418	106,473	19,641,014	1.7	2.4

[1] "Review of the Safety and Economic Aspects of Increased Vehicle Sizes and Weights," unpublished report, *Federal Highway Administration*, Washington, D.C., September 1969.
[2] The numbers of *vehicle involvements* in accidents for vehicles of all types were estimated from actual numbers of *accidents*, which were furnished.

1 mile = 1.61 km

In 1975, BMCS accident data were used to analyze severity rate as a function of truck weight. (*4*) Car-truck accidents were examined, and injuries per accident and fatalities per accident were calculated for both truck and car occupants. A clear relationship was found between truck weight and the fatality rate for car occupants. Unfortunately, these data, as in previous analyses, included a range of truck and road types, making it impossible to assess the effect of truck weight alone.

In a similar analysis conducted in 1977, BMCS data again were used to examine the effect of certain variables on the number of car occupant fatalities in car-truck accidents. (*5*) Several variables were considered, including year of accident, urban or rural location, roadway, and truck type and weight. A contingency table analysis was used to predict the probability of a fatality. It was found that the probability of a fatality could be predicted accurately from the location and the roadway (as described by the number of lanes). Once the location and roadway combination was known, the probability of a fatality did not vary significantly with truck type or weight. This conclusion supports the need to control for road type and location when comparing the accident experience of trucks or other vehicles.

Specific size and weight safety studies

Doubles/singles comparisons

In 1977, BMCS analyzed accident and vehicle-kilometre (vehicle-mile) data submitted by seven large motor carrier firms for a 7-year period. (*6*) A comparison of accident and severity rates of singles and doubles showed no differences (table 2). Again, no effort was made to separate data by region of the United States to assure equal exposure of the two truck types. Also, the seven carrier firms surveyed were among the largest common and private carriers in the Nation and, as such, operated modern, well-maintained equipment driven by experienced drivers and had active safety programs. Although

Table 2.—Safety comparison of doubles versus singles (*6*)

Year and truck type		Accidents per million vehicle-miles	Injuries per million vehicle-miles	Fatalities per million vehicle-miles	Property damage per million vehicle-miles	Injuries per accident	Fatalities per accident	Property damage per accident
					Dollars			*Dollars*
	Doubles	0.572	0.307	0.066	0.0043	0.537	0.116	7,500
1976	Singles	0.848	0.605	0.056	0.0060	0.713	0.066	7,100
	Doubles	0.733	0.483	0.030	0.0075	0.660	0.041	10,240
1975	Singles	0.707	0.566	0.079	0.0058	0.800	0.111	8,162
	Doubles	0.590	0.495	0.050	0.0039	0.838	0.085	6,665
1974	Singles	0.880	0.688	0.046	0.0057	0.783	0.052	6,440
	Doubles	0.761	0.492	0.041	0.0047	0.646	0.054	6,224
1973	Singles	0.940	0.723	0.078	0.0066	0.769	0.082	7,002
	Doubles	0.660	0.550	0.048	0.0035	0.833	0.073	5,269
1972	Singles	0.795	0.745	0.081	0.0041	0.937	0.101	5,217
	Doubles	0.640	0.554	0.049	0.0042	0.865	0.076	6,506
1971	Singles	0.768	0.699	0.049	0.0050	0.910	0.064	6,442
	Doubles	0.624	0.533	0.062	0.0037	0.853	0.100	5,972
1970	Singles	0.963	0.925	0.070	0.0052	0.961	0.073	5,305
	Doubles	0.529	0.495	0.039	0.0022	0.935	0.074	4,201
1969	Singles	0.845	0.997	0.064	0.0039	1.180	0.076	4,624

1 mile = 1.61 km

the data are representative of large, modern truck fleets, they do not necessarily represent that portion of the truck population with older, poorly maintained equipment, inexperienced drivers, and no safety programs. In addition, these carriers run their trucks loaded about 95 percent of the time. As discussed later in this article, there is evidence that combination trucks, especially doubles, may experience serious safety problems when empty.

Recently the accident data of another large motor carrier firm was analyzed as part of a court case involving the use of doubles.[3] Highway links where this firm ran both singles and doubles were selected for study, but the report did not present criteria used in the selection. For each link, an equal number of trips involving singles and doubles were matched, and the firm's records were searched for accidents occurring on these trips. In this way, accident rates for the two truck types could be calculated with the exposure being controlled for road type, urban or rural location, and region of the United States (table 3). The analysis indicated that for this carrier firm there was no difference in the accident experience of singles and doubles. Again, however, these data may represent accurately this firm's experience with the operation of doubles but not represent the overall experience of doubles. Like most other common carriers, this firm ran virtually no empty trucks.

An analysis conducted for FHWA in 1978 used data from the State of California to assess the relative safety of singles and doubles. (*7*) Accident data from 1974 were combined with estimates of truck exposure to calculate accident and injury rates based on vehicle-kilometres (vehicle-miles) of travel. Estimates also were made of average cargo weight to evaluate the safety of the two vehicles based on cargo kilogram-kilometres (ton-miles) of travel. The analyses indicated that on a vehicle-kilometre (vehicle-mile) basis, the only significant difference was a higher fatality rate for doubles. In the kilogram-kilometre (ton-mile) comparison, the only significant differences were a higher accident rate and injury rate for singles. These figures are shown in table 4.

The accuracy of the exposure estimates used in this study is questionable. The accident data came mostly from rural locations while the classification counts used to estimate exposure came from both rural and urban locations. If only rural classification counts had been used, the exposure estimate would have been different, which would have changed the findings of the study. Because there are some urban accidents in the data base, it is not clear which method of calculating exposure would have been most appropriate.

[3] John Glennon, "Matched Pair Analysis," unpublished report, *Consolidated Freightways Corporation.*

Table 3.—Accidents for singles and doubles[1]

Truck type	Total trips	Total miles	Total fatal accidents	Total injuries	Total accidents
Singles	188,296	56,100,018	1	27	100
Doubles	188,296	56,100,018	1	17	106

[1] John Glennon, "Matched Pair Analysis," unpublished report, *Consolidated Freightways Corporation.*

1 mile = 1.61 km

Table 4.—Accident involvement rates of singles and doubles (*7*)

Type of rate	Singles	Doubles	Rates significantly different[1]
Per 100 million vehicle-miles			
Accident involvements	146.4	148.9	No
Injuries	62.1	63.5	No
Fatalities	3.8	5.3	Yes
Per 100 million ton-miles			
Accident involvements	14.70	11.0	Yes
Injuries	6.30	4.7	Yes
Fatalities	0.38	0.4	No

[1] Significantly different at the 0.05 level.

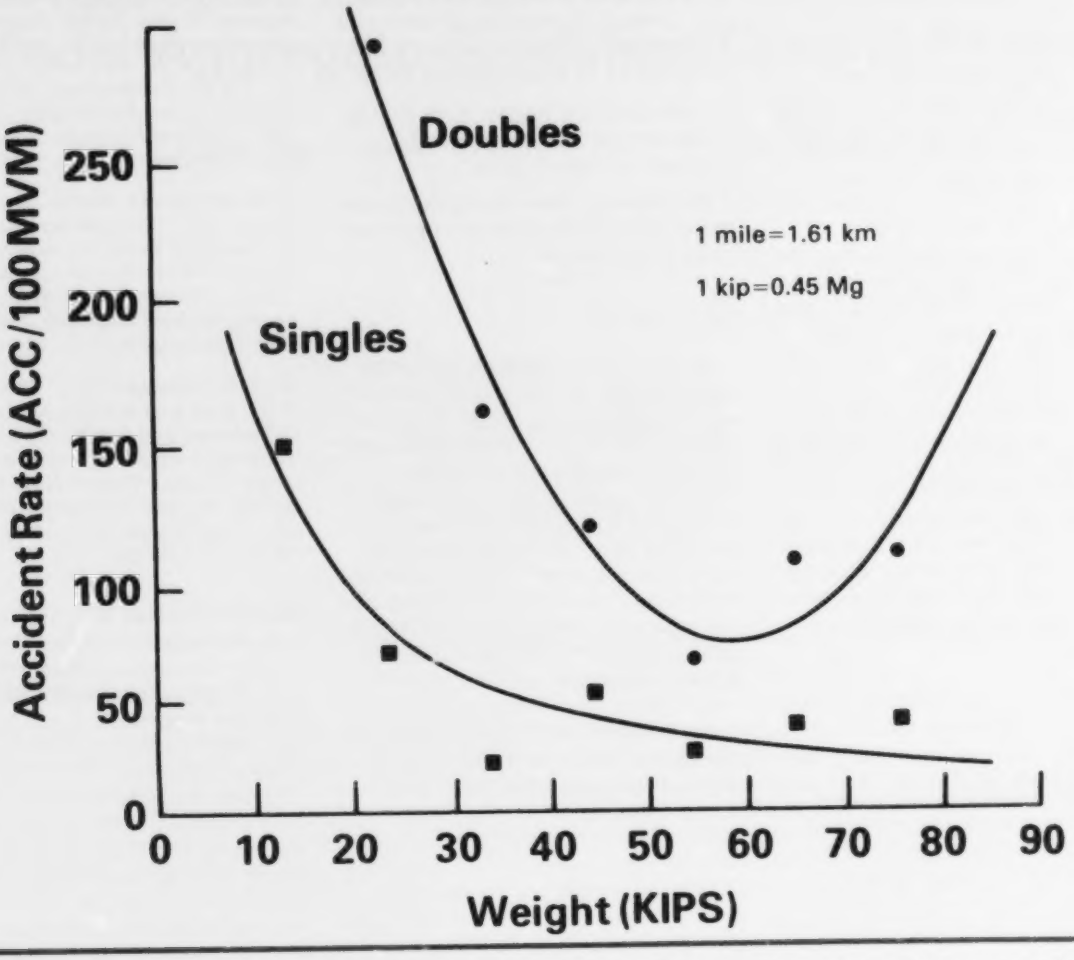
1 mile = 1.61 km
1 ton = 0.91 Mg

Comprehensive truck-accident study

In 1975, FHWA initiated a comprehensive study to assess the effect of truck size and weight on accident experience. (*8*) Steps were taken to avoid some of the problems inherent in previous truck accident research.

Six States—California, Nevada, Texas, Michigan, Pennsylvania, and Maryland—were selected for study based on annual truck exposure, historical accident records, and kinds of vehicles allowed to operate. Within these six States, 78 road segments were selected to represent a range of road types (freeway, primary, and secondary) and locations (urban and rural). Historical accident experience was used as a site selection criterion to avoid a bias toward either high- or low-accident sites. Truck volumes also were checked to insure reasonable volumes.

Figure 2.—Accident rates versus gross vehicle weight for singles and doubles. (8)



Exposure data were developed from several sources. State average daily traffic data were used as the base. Photographic classification counts were made every 3 months at each site to determine the distribution of truck types. At sites with truck scales or truck stops, more detailed information concerning vehicle dimensions, weight, and driver characteristics were collected periodically by field investigators to calculate vehicle-kilometres (vehicle-miles) of travel for a variety of vehicle and driver descriptors.

Each week field investigators reviewed police reports for truck accidents that occurred within the boundaries of any of the sites and investigated these accidents in detail. Investigators visited the sites, contacted the people involved in the accident, and, if possible, inspected the truck involved in the accident. Data were collected on the truck, the other vehicle(s), all drivers, the location, and the dynamics of the accident.

Accident and exposure data were collected for 1½ years in 1976–1977. The final accident file consisted of 2,112 records of trucks involved in 1,816 accidents. (*8*) When an accident involved more than one large truck, a record was established for each truck. Consequently, even though the report uses the term "accidents," these are really truck accident involvements. Most of the analyses compared truck accident involvement rates.

This comprehensive effort resulted in two major findings. First, doubles had a significantly higher accident involvement rate than singles (table 5). Second, empty combination trucks, particularly empty doubles, had a substantially higher accident involvement rate than loaded combinations (fig. 2).

Table 5.—Distribution of accident rates for singles and doubles by roadway type (*8*)

Truck type	Rural		Urban	
	Freeway	Nonfreeway	Freeway	Nonfreeway
Singles	110	99	214	93
Doubles	228	468	388	428

Although doubles may be operated safely under controlled conditions (for example, rigid permit regulations or active fleet safety efforts), when operated under a variety of conditions by a variety of operators with no special controls, the first finding indicates that doubles appear to have unique safety problems. The second finding indicates that operating empty doubles may be especially hazardous. When loaded, there is less difference in the accident experience of singles and doubles. The fact that large common carriers rarely run empty vehicles may account, in part, for the difference in the results of this study and those in the BMCS analysis (*6*) and the motor carrier firm analysis.[4] As a result of these findings, ongoing work has been redirected to emphasize braking and handling capabilities of empty and near-empty doubles and singles.

Other interesting findings in this FHWA study include the following:

- Doubles have a significantly higher kilogram-kilometre (ton-mile) accident involvement rate than singles on urban freeways and rural nonfreeways. There is no significant difference on other road types.
- There is no significant difference in the accident rate of tractor-trailer combinations with conventional tractors and those with cab-over-engine tractors.
- There is no significant difference in the accident rates of tractor-trailer combinations with 12.2 m (40 ft) trailers and those with 13.7 m (45 ft) trailers.
- Truck drivers under age 20 have the highest accident rate, followed by drivers 20 to 29 years of age, and 60 years and older.
- There is no significant difference between drivers of singles and drivers of doubles in terms of age, professional experience, or experience in their kind of truck.
- Combination trucks with dump- or tank-type trailers have the highest accident rates.
- At freeway interchanges, trucks have more accidents at offramps than at onramps.

Conclusion

The available research on large truck safety is not always congruent for several reasons. Often, apparently conflicting results actually involve different issues or different populations of trucks. Also, the quality of the data or analysis is sometimes questionable. It does seem clear, however, that larger and heavier trucks can be operated safely, but under certain conditions, larger trucks do have real safety problems. It is imperative that these problems be addressed and that acceptable solutions be developed so that these highly productive trucks can be operated safely on our Nation's highways.

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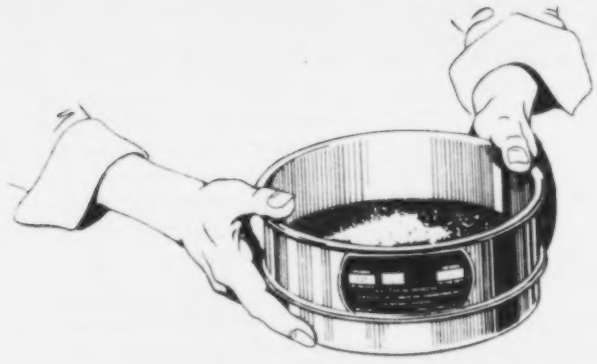
Aggregate Gradation Control: Part II— A Model Aggregate Gradation Control Program

by
Peter A. Kopac, Jose I. Fernandez, Stephen W. Forster, and Terry M. Mitchell



Introduction

This is the conclusion of a two-part article on a Federal Highway Administration (FHWA) field investigation of aggregate gradation control. Part I, published in the June 1982 issue of *Public Roads* (*1*)[1], presented an analysis of the relative costs of current gradation control programs of State highway agencies. (*2*) The analysis indicated that quality assurance-quality control (QA–QC) programs in which the contractors or producers perform most of the gradation testing are more economical than the more widely used "traditional" programs in which the State highway agencies perform most of the testing.

As a result of the analysis, a model aggregate gradation control program was developed by combining some new concepts with the most favorable and economical features of the State programs that were studied. (*2*) This article, Part II, describes this model program.

Key Considerations in Developing the Model Program

Economy

The primary objective of a gradation control program should be to promote and maintain aggregate quality with respect to gradation. Many kinds of gradation control programs can maintain acceptable aggregate quality, but an *economical* gradation control program should maintain quality while minimizing the testing-related costs for all parties involved.

[1]Italic numbers in parentheses identify references on page 60.

Point of delivery

Because a gradation control program should promote and maintain the quality of the delivered aggregate, acceptance testing should be performed whenever possible at the point of delivery—that point where the aggregate is incorporated into the concrete mixture, or into the project in the case of unbound aggregate. Although gradation control testing should be performed at various stages in the production, transportation, and handling of the aggregate, it is suggested that State highway agencies not prescribe the details of such testing. Aggregate producers should be free to perform whatever testing they find consistent with process control and the protection of their contractual interests. State highway agencies also should be concerned primarily with protecting their contractual interests, and this can be done best by testing at the point of delivery.

For aggregates being used directly as base, subbase, or shoulder material, point of delivery is the project site itself. For aggregates being used for portland cement concrete or for bituminous concrete, point of delivery is the concrete plant. If possible, aggregate should be sampled at the plant at the last feasible point (for example, at a hopper or conveyor belt) before the aggregate is used. This way the effects of handling the aggregate in the production, transportation, and storage stages would be reflected in the test results.

Testing at the aggregate source, although convenient and popular in many States, does not always reliably indicate product gradation at the point of use. Material that is found acceptable at the aggregate production plant may not be within the specified gradation range when it arrives at the construc-

tion site or the concrete plant. By accepting the aggregate at the point of use only, State highway agencies are not involved with intermediate points of testing and rely on contractors to insure that the aggregate processing will result in the specified material.

Contractor quality control

A distinction must be made between acceptance testing and process control testing. All process control testing should be performed by the contractor so that contract responsibilities are maintained. The contractor's own forces or those of the subcontractor or supplier may be used to perform the process control functions. The services of an independent testing laboratory also may be used. In any of these cases, the contractor is still responsible for insuring adequate process control.

State highway agency quality assurance

A State highway agency could perform all acceptance testing independently of a contractor's process control testing. However, by using a QA–QC approach, test results from the contractor's quality control program can be used directly for acceptance if the results can be validated by a concurrent program of quality assurance that includes verification testing. This approach results in the least amount of duplication.

Verification test results should not be used directly for acceptance. They should be used only to verify and maintain the reliability of the contractor's test data. Material acceptance would be affected by verification test results only if the test results consistently, and excessively, varied from those of the contractor, indicating poor reliability of the contractor's data.

Acceptance criteria

Establishing gradation tolerances for acceptance of delivered aggregate is not the same as establishing gradation tolerances for acceptance of concrete mixtures. Gradation tolerances for aggregate generally include a wide band of acceptance percentages whereas gradation tolerances for mixtures must conform to a target or design percentage. The problem is more complicated in the case of aggregate acceptance.

Many aggregate gradation acceptance plans include terms such as "substantial compliance" or "reasonably close conformity" without defining them. In setting tolerances for acceptance of aggregate gradation, both the magnitude and frequency of the noncompliance must be considered. For the purpose of this model program, the magnitude of the aggregate's nonconformance to specification limits is measured in terms of Tolerance Increment Factors (TOL's). As illustrated in figure 1, TOL's are expressed as percentages and represent the increments of tolerance based on percentage of total test sample weight. TOL's are applied to each end of the specified gradation range for each sieve size. It is postulated that the maximum allowable nonconformance for any single test is 2 TOL's from the prescribed limits of the gradation range. More stringent tolerances also are applicable based on frequency of noncompliance as discussed later. For the sake of simplicity, the model program structure refers only to TOL's without designating their specific values. Specific TOL values of 2 percent for the minimum sieve size and 4 percent for most other sieve sizes are suggested. However, State highway agencies that have studied aggregate variability resulting from sampling and testing error may want to assign values more suited to their particular situations. Although a new concept, the use of TOL's in the specifications clearly delineates the consequences for various degrees of deviation from the allowable gradation bands.

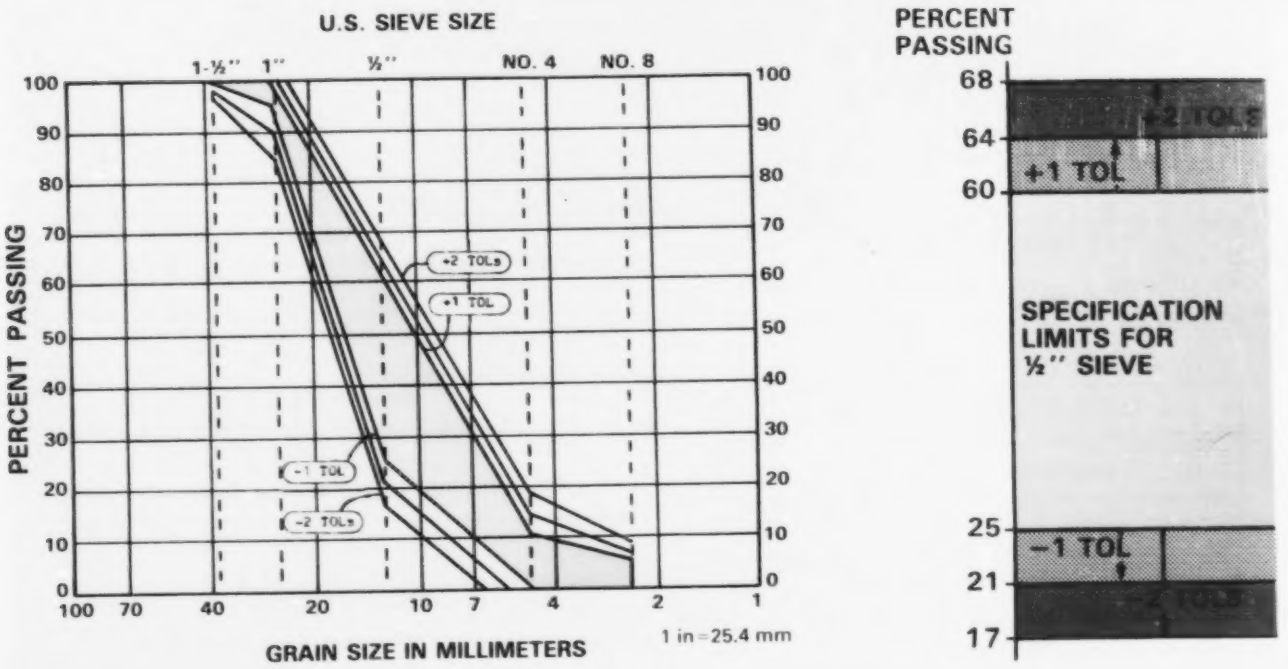
Similar criteria are applied when comparing quality control tests with verification tests to determine the reliability of the contractor's quality control program. In comparing the results of quality control tests and verification tests, the difference between results for the same sieve size generally should be within 1 TOL and in all cases within 2 TOL's. This means that up to one increment of tolerance would be considered normal, but no more than two increments would be acceptable if the contractor's results are to be considered reliable.

Treatment of noncompliance

In the FHWA field investigation it was found that without a method for evaluating "substantial compliance," State highway agency personnel are unwilling to apply a price reduction to what is perceived as a "minor" deviation from the prescribed gradation limits. Price adjustments, however, usually are necessary to encourage the contractor to maintain adequate gradation control. State highway agencies should vigorously enforce their price adjustment policies if their gradation control programs are to be effective and fair to all contractors. The model gradation control program attempts to lessen this subjective element by quantifying not only the magnitude but also the frequency of deviation from the nominal gradation range.

The model program's price adjustment approach involves assigning a unit value to the quantities of aggregate to be used in each particular application within the scope of the contract. Such unit values should be assigned by the State highway agency for inclusion in the contract documents and could be related to the replacement costs or the expected loss of serviceability of the product or portion of the structure in which the aggregate is used. Using this approach, outright rejection could require removal and replacement of the defective material, while price reduction provisions would entail progressively greater reductions of payment based on the cor-

Figure 1.—The effect of TOL's on a gradation band.



responding unit value, depending on the severity of noncompliance. The payment reduction percentages suggested in the model program are guidelines only; each State highway agency should tailor the price reduction provisions to its individual situation. In keeping with the differentiation of contractual relationships, the State should not attempt to assign responsibility for the nonconforming aggregate which resulted in price reductions.

Model Program Structure

The model aggregate gradation control program that was developed based on the preceding key considerations is summarized in figures 2 and 3. The program places responsibility for process control on the construction contractor and prescribes the minimum amount of testing that must be performed by the contractor. Also, the program emphasizes point-of-use testing to minimize sample transportation costs while allowing the contractor's test results to be used, subject to adequate reliability, for acceptance.

Some of the major requirements of the model program follow.

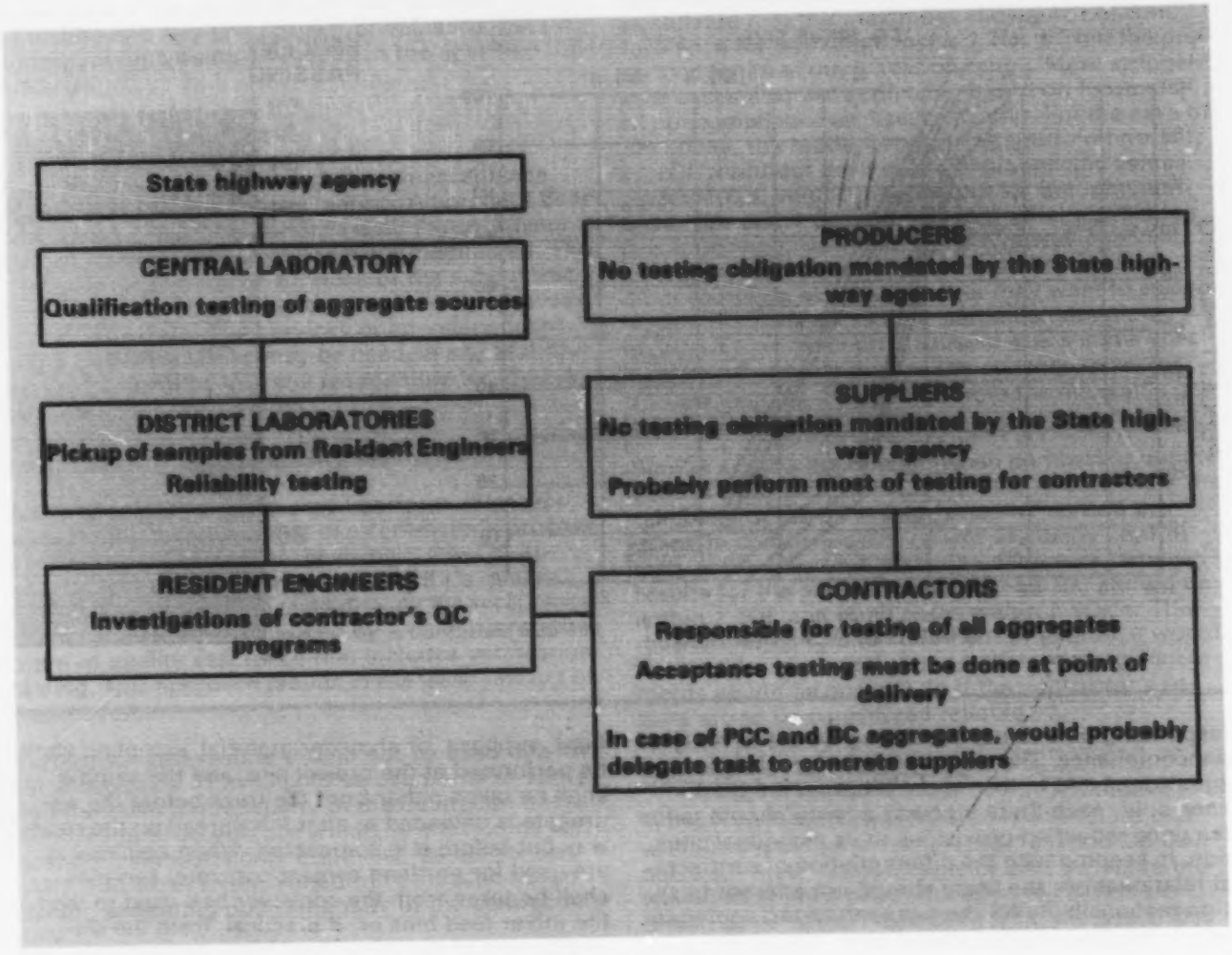
Place of sampling

Aggregate samples shall be taken at the last feasible point before using the aggregate or mixing it with other ingredients. When aggregates are used for base, subbase, or shoulder material, sampling shall be performed at the project site, and the sample shall be taken either from the truck before the aggregate is unloaded or after it is spread on the roadway but before it is compacted. When aggregates are used for portland cement concrete, samples shall be taken from the conveyor belt used to load the mixer feed bins or, if practical, from the discharge end of the mixer feed bins. Aggregates used for bituminous concrete mixes shall be sampled at the conveyor belt carrying the individual aggregate classes into the cold-feed blend. All samples shall be split to provide material for verification testing by the State highway agency.

Sampling and testing frequency

For aggregates used for bituminous concrete or portland cement concrete construction, one set of "startup" samples (a set is three samples taken at the same time) shall be taken and one sample tested within the first 30 minutes of operation of the concrete plant each day. Rapid drying methods will be permitted for this test. If this initial test shows the aggregate to be nonconforming and the results are confirmed by retesting as described below, adjustments may be made, a new set of samples taken, and one sample tested within 30 minutes after adjustments are made. The test results of the first set of samples would be marked clearly with the time period represented and the adjustments that were made based on the test results. The test results of

Figure 2.—Schematic diagram of the model gradation control program.


State highway agency
CENTRAL LABORATORY
Qualification testing of aggregate sources
DISTRICT LABORATORIES
Pickup of samples from Resident Engineers
Reliability testing
RESIDENT ENGINEERS
Investigations of contractor's QC programs
PRODUCERS
No testing obligation mandated by the State highway agency
SUPPLIERS
No testing obligation mandated by the State highway agency
Probably perform most of testing for contractors
CONTRACTORS
Responsible for testing of all aggregates
Acceptance testing must be done at point of delivery
In case of PCC and BC aggregates, would probably delegate task to concrete suppliers

the first set would not be considered in the acceptance criteria, but the results of the second set would be. Two additional sets of samples shall be taken at random each day—one during the morning hours and one during the afternoon hours. If a set of samples is taken after startup adjustments, it shall be considered the morning sample.

For aggregates used as base or subbase material, a set of samples shall be taken and one sample tested from one of the first three trucks each day, with an additional set of samples taken approximately every 900 Mg (1,000 tons) or fraction thereof delivered the same day.

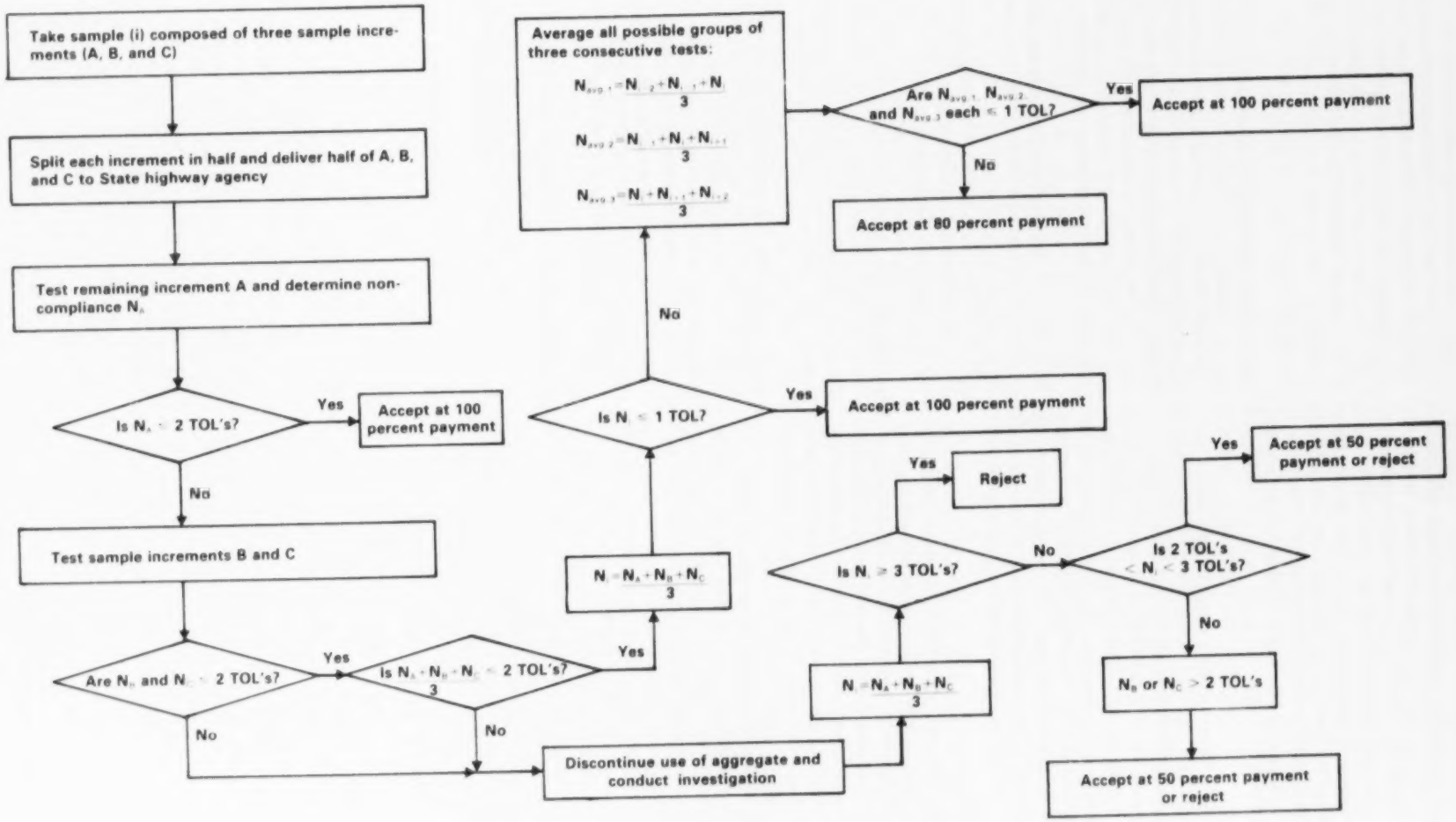
For aggregates used for road shoulders, one set of samples shall be taken from one of the first three trucks each day, and one additional set of samples shall be taken at random during the day each day.

All sampling shall be performed by the contractor or an authorized representative. Before testing, all samples shall be split using an approved splitting device. One-half of each sample shall be placed in a tight burlap or heavy plastic bag, tied with a nonremovable closure, identified, and immediately delivered to the designated representative of the State highway agency at the project site. The other half of one of the samples in a set shall be tested as soon as possible but at least within 2 hours after sample collection. The halves of the other two samples of the set shall be stored temporarily for retesting, if necessary.

Retesting by the contractor

If test results indicate a noncompliance of more than 2 TOL's with respect to any size of the gradation specification, the two other samples of the same set shall be tested immediately. If both of these samples show the aggregate to have a noncompliance of no more than 2 TOL's with respect to all sieve sizes, the results of the tests on all three samples of the set shall be averaged, sieve by sieve. If the resulting averages show the aggregate to

Figure 3.—Flow chart showing acceptance and payment criteria for model gradation control program.


Take sample (i) composed of three sample increments (A, B, and C)
Split each increment in half and deliver half of A, B, and C to State highway agency
Test remaining increment A and determine noncompliance N_A
Is N_A ≤ 2 TOL's?
Yes
Accept at 100 percent payment
No
Test sample increments B and C
Are N_B and N_C ≤ 2 TOL's?
Yes
Is $\frac{N_A + N_B + N_C}{3}$ ≤ 2 TOL's?
Yes
$N_i = \frac{N_A + N_B + N_C}{3}$
No
No
Discontinue use of aggregate and conduct investigation
Average all possible groups of three consecutive tests:
$N_{avg.1} = \frac{N_{i-2} + N_{i-1} + N_i}{3}$
$N_{avg.2} = \frac{N_{i-1} + N_i + N_{i+1}}{3}$
$N_{avg.3} = \frac{N_i + N_{i+1} + N_{i+2}}{3}$
Are $N_{avg.1}$, $N_{avg.2}$ and $N_{avg.3}$ each ≤ 1 TOL?
Yes
Accept at 100 percent payment
No
Accept at 80 percent payment
Is N_i ≤ 1 TOL?
Yes
Accept at 100 percent payment
No
$N_i = \frac{N_A + N_B + N_C}{3}$
Is N_i ≥ 3 TOL's?
Yes
Reject
No
Is 2 TOL's < N_i < 3 TOL's?
Yes
Accept at 50 percent payment or reject
No
N_B or N_C > 2 TOL's
Accept at 50 percent payment or reject

have a noncompliance of no more than 2 TOL's with respect to all sieve sizes, only the average will be considered for the project records. If either of the other two samples, or the average of the three samples, shows noncompliance of more than 2 TOL's with respect to any sieve size, the contractor immediately shall discontinue using the aggregate until an investigation and corrective measures can be undertaken. In all cases, the results of all three tests shall be submitted together.

QA testing by the State highway agency

The State technicians shall test, at random, 1 sample out of every 10 sets of samples submitted by the contractor. In addition, one sample out of each set for which results were averaged by the contractor shall be tested. In general, these verification tests by the State highway agency should be completed within 3 days, and in all cases within 1 week, of receipt from the contractor of the last sample of each group of 10 sets.

If the State's test results consistently agree with the contractor's, within 1 TOL with respect to all sieve sizes, the reliability of the contractor's QC program shall be considered good. If a discrepancy of more than 1 but no more than 2 TOL's with respect to any sieve size is observed, the reliability of the contractor's QC program shall be considered only fair and the State's testing frequency shall be increased to one sample out of every five sets of samples (including one sample retroactive to the middle of the previous 10-set period) until three consecutive samples fall within the definition of good reliability. If a discrepancy of more than 2 TOL's with respect to any sieve size is observed or whenever three consecutive samples fall within the characteristics of fair reliability, the reliability of the contractor's QC program shall be considered poor. Verification testing will be increased and the matter shall be referred to the Resident Engineer responsible for the project for possible payment reduction. Depending upon the results of the investigation, the State highway agency shall have the option of performing all QC testing and assessing a penalty against the contractor for having to do so.

Acceptance criteria

Aggregate acceptance shall be based only on the contractor's test results, with the State's test results being used only to verify the reliability of the contractor's results. Aggregate showing noncompliance of 1 TOL or less with respect to all sieve sizes shall be accepted without question. Aggregate showing noncompliance of more than 1 TOL but no more than 2 TOL's with respect to any sieve size also shall be accepted without question if the averages of the test results sieve by sieve, for all possible groups of three consecutive tests including the test in question, yield an average noncompliance of no more than 1 TOL with respect to all sieve sizes.

When the averaging requirements are not met, the aggregate could still be accepted subject to price reduction. However, when the results of a single test show any nonconformance of more than 2 TOL's with respect to any sieve size, the Resident Engineer may, based on the specific test results (including the results of the retest samples), reject the aggregate or accept it subject to price reduction.

When the contractor's test results show good reliability, acceptance decisions can be based only on the contractor's results. When the contractor's test results show fair or poor reliability, the Resident Engineer should request the State laboratory to test specific samples to determine if a price reduction for the aggregate is applicable, in addition to the possible penalty for poor reliability.

In any event, if the results of tests on any single set of samples, verified by the test on one of the State's split samples, show a nonconformance of 3 TOL's or more on any sieve size, the Resident Engineer should immediately reject the aggregate and direct its removal and replacement.

Payment criteria

Price reductions shall apply to aggregate delivered when the contractor's test results show poor reliability as well as to accepted but nonconforming aggregate. Table 1 shows the possible price reductions for these two cases.

A price reduction of 10 percent (based on the assigned unit prices) shall be applied to aggregate delivered when the contractor's quality control program shows poor reliability. This provision shall be applied regardless of the actual test results obtained by the contractor.

Table 1.—Basic price reduction levels for the model program

State's reliability (verification) tests	
	Percent reduction
Good reliability	0
Fair reliability	0
Poor reliability	10
Contractor's acceptance tests	
	Percent reduction
Single test:	
Nonconformance < 2 TOL's	0
More than one test required:	
Nonconformance ≤ 1 TOL	0
1 TOL < nonconformance ≤ 2 TOL's	20
2 TOL's < nonconformance < 3 TOL's	50 or reject
Nonconformance ≥ 3 TOL's	reject

A price reduction of 20 percent shall be applied to aggregate showing nonconformance of more than 1 TOL but no more than 2 TOL's with respect to any sieve size and which failed to meet the acceptance criteria for the average of all possible groups of three consecutive tests including the test in question as defined above.

A price reduction of 50 percent shall be applied for accepted aggregate showing noncompliance of more than 2 TOL's but less than 3 TOL's with respect to any sieve size. The same 50 percent reduction will be applied to any aggregate, if accepted, delivered before operations are stopped when any retest sample in a set shows noncompliance of more than 2 TOL's with respect to any sieve size. It should be noted that any aggregate for which the 50 percent reduction applies also could be rejected by the Resident Engineer, based on the specific test results and the results of the retest samples.

Finally, no payment will be made for any aggregate showing noncompliance of 3 TOL's or more with respect to any sieve size. Such aggregates should be rejected and replaced unless it is determined that the quantities involved are very small and will not significantly compromise the safety, function, or durability of the structures in which the aggregate will be used.

The price reduction scheme discussed above is very basic and has few distinct payment levels. A State highway agency, however, may want to make finer distinctions among quality levels and thereby develop a scheme having more payment levels. This can be done by making a distinction between aggregate showing a nonconformance on one sieve size only and aggregate showing nonconformances on two or more sieve sizes. (In the model program, the largest nonconformance governs for acceptance and payment purposes.)

Summary and Discussion

The model aggregate gradation control program presented in this article incorporates the most desirable features of the State programs investigated in the FHWA study. The overall costs of the model program should be comparable to, or perhaps slightly higher than, those of the contractor-oriented (State B) gradation control program investigated in Part I of this article. The responsibility for testing and place of testing are the same in the model program and the State B program and therefore should result in similar labor costs. The key to economy in labor costs appears to be in effectively integrating gradation testing activities by contractor technicians with other responsibilities. One area where the model control program might yield slightly higher costs than the State B program is verification testing because the model program incorporates a slightly more involved plan of verification testing by the State. This is justified, however, because of enhanced reliability of the contractor's test results.

The model program introduces several new features. Although none of these features is absolutely essential, there are good reasons for their use and they should be considered. (If a State highway agency desires, individual features may be replaced with more commonly accepted methods.) One of these new features is the use of TOL's to allow for gradation variability resulting from gradation sampling and testing error. Their use enables the State highway agency to treat out-of-specification gradations as objectively as possible. Another unique feature is the application of price reductions when the State's verification test results disagree with the contractor's results. Instead of applying verification price reductions, the State could either shut down the contractor's operation or assign its own full-time inspectors to the work at the contractor's expense. The State highway agency should not have to incur additional costs because of inaccurate or faulty contractor testing and certainly should not direct process control operations.

A final unique feature is acceptance of the gradation of bituminous concrete aggregate before it has been incorporated into the mix. Although improper mixing proportions may occur after the aggregate has been sampled, this feature has been found acceptable for portland cement concrete and is appealing because larger sample sizes, and therefore greater accuracy, are possible.

The Federal Highway Administration is encouraging State highway agencies to consider the ideas contained in this model program. FHWA's Office of Implementation is soliciting State highway agencies to conduct economic analyses of their own gradation testing programs, as outlined in Part I of this article, and to try the model program (or similar contractor control programs already in use in some States) in one or more districts in their States.

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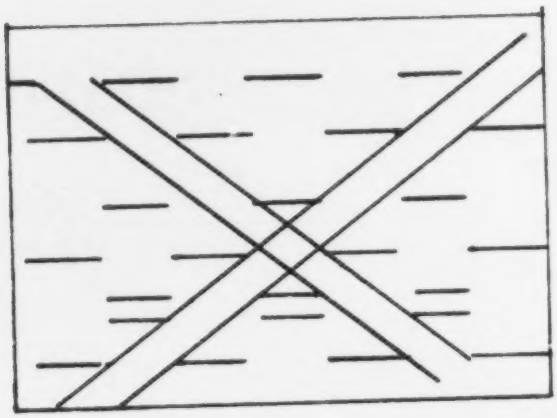
The MAXBAND Program for Arterial Signal Timing Plans

by

S. L. Cohen and J. D. C. Little



This article discusses the MAXBAND model, a portable bandwidth optimization computer program written in FORTRAN IV that can be used to develop signal timing plans for signalized arterials and simple networks of three intersecting arterials. The program can optimize signal offset, cycle length, and left turn phase sequence. The program has several features that can improve the efficiency of timing plans. These features include varying the progression speed on individual street segments, advancing the start of green at each intersection to allow queue clearance, and permitting the user to specify the weighting of the bands in each direction on two-way arterials to give preference to the direction of heavier traffic flow.

Introduction

Maximizing green bandwidth has been the most widely used method for developing signal timing plans for signalized arterials. This method is relatively straightforward and has been popular because it is based on street geometry and does not require traffic data, making it easier to use than delay optimization programs such as TRANSYT. (*1*)[1] Field observation of bandwidth optimized signal systems indicates the systems perform well. (*2*)

In simple cases, such as one-way progression or equal signal spacing, good results may be obtained manually using time-space diagrams. However, in more complicated situations, such as two-way progression with unequal block spacing or determining other parameters (left turn phase sequence and cycle length) in addition to offset, using time-space diagrams becomes prohibitive. Thus, several computer programs (*3*)[2] have been developed in the past few years to handle more complicated cases. The most recent program to be developed is MAXBAND. (*4*)

MAXBAND is based on a maximal bandwidth criterion that enables the common cycle length, offsets, and left turn phase sequence at each intersection to be computed to maximize a weighted sum of the through green bandwidths in each direction. (*5*) The percentage of green time for each phase may be entered by the user or computed by the program using a method in which the user enters volumes and capacities. (*6*) If the user enters green times, no traffic data are required to execute the program.

[1] Italic numbers in parentheses identify references on page 65.

[2] "Timing Support Programs–SIGART," Section 6, unpublished report, *JHK & Associates,* Alexandria, Va.

Program Features

MAXBAND has the following features that increase its utility and improve the efficiency of the signal timing it computes:

- The program uses an input structure, based on the widely used SOAP program (*7*) that is designed to analyze intersection design and signal timing.
- The program allows the design speeds to vary on each block within fixed limits set by the user. This capability can improve substantially the efficiency of bandwidth solutions by taking advantage of the observation that drivers will make limited changes to their speeds to adjust to signal timing.
- The program has a green advance feature, which may be set by the user, that allows the mainline green at a given intersection to be started early. Green advance allows a standing queue formed from the secondary flow of an upstream intersection to be discharged.

• The program can select the arterial left turn phase sequence pattern at each intersection, which maximizes the through green band. The selection can be made from four possible patterns: lead-lead (leading left turns in both directions); lead-lag (leading green inbound, lagging green outbound); lag-lead (lagging green inbound, leading green outbound); and lag-lag (lagging left turns in both directions). The user may limit which patterns are to be tried. The left turn phase times do not need to be the same in both directions.

• Because the program maximizes the weighted sum of the bandwidth in each direction, the user may adjust the weighting factor to give preference to either direction.

• The program can select, from a continuous range specified by the user, the common cycle time that optimizes the weighted sum of bandwidths on an arterial or a triangular network of three intersecting arterials.

• The user may specify green phase time. Using this alternative, the program can be executed using only geometric data Because traffic data are expensive to collect, this will result in a substantial savings over a program like TRANSYT, which requires traffic data.

Program Formulation

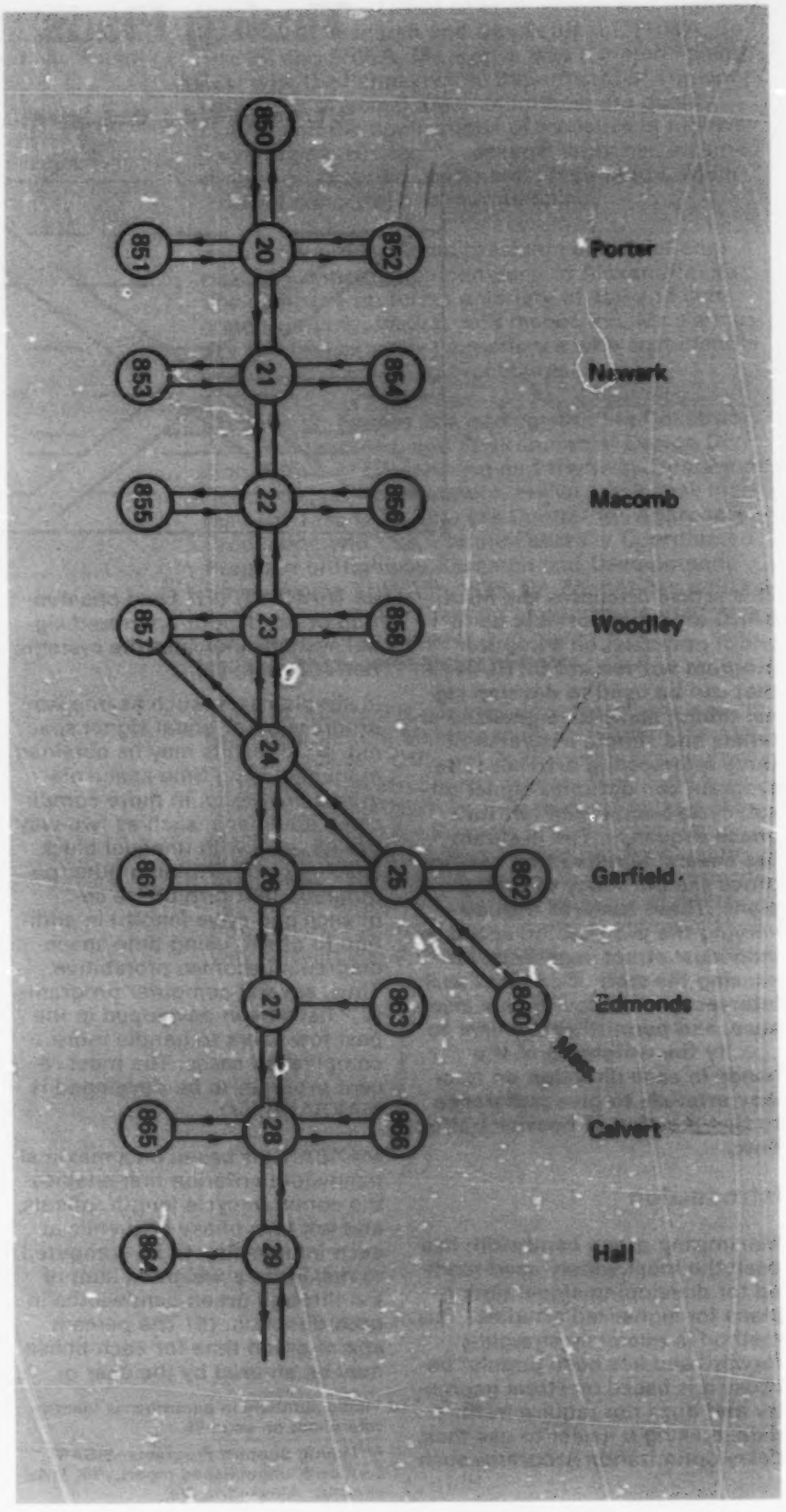
The mathematical formulation of the MAXBAND program is derived from the following observations:

1. The sum of the offsets around any closed loop in the network must be an integer multiple of the cycle length. (*8*) For example, in figure 1 a closed loop is from node 21 to node 22 and back to node 21.

2. The bandwidth in either direction on a two-way arterial cannot exceed the shortest green time on the arterial facing in that direction.

It then can be shown that the maximal bandwidth problem can be stated as a mixed integer linear programing problem: Find the

Figure 1.—Link-node diagram for Wisconsin Avenue arterial, Washington, D.C.



values of the bandwidth in both directions, the cycle length, the offsets, and the phase sequence to maximize the objective function given by the weighted sum of the bandwidth in both directions subject to the two constraints above.

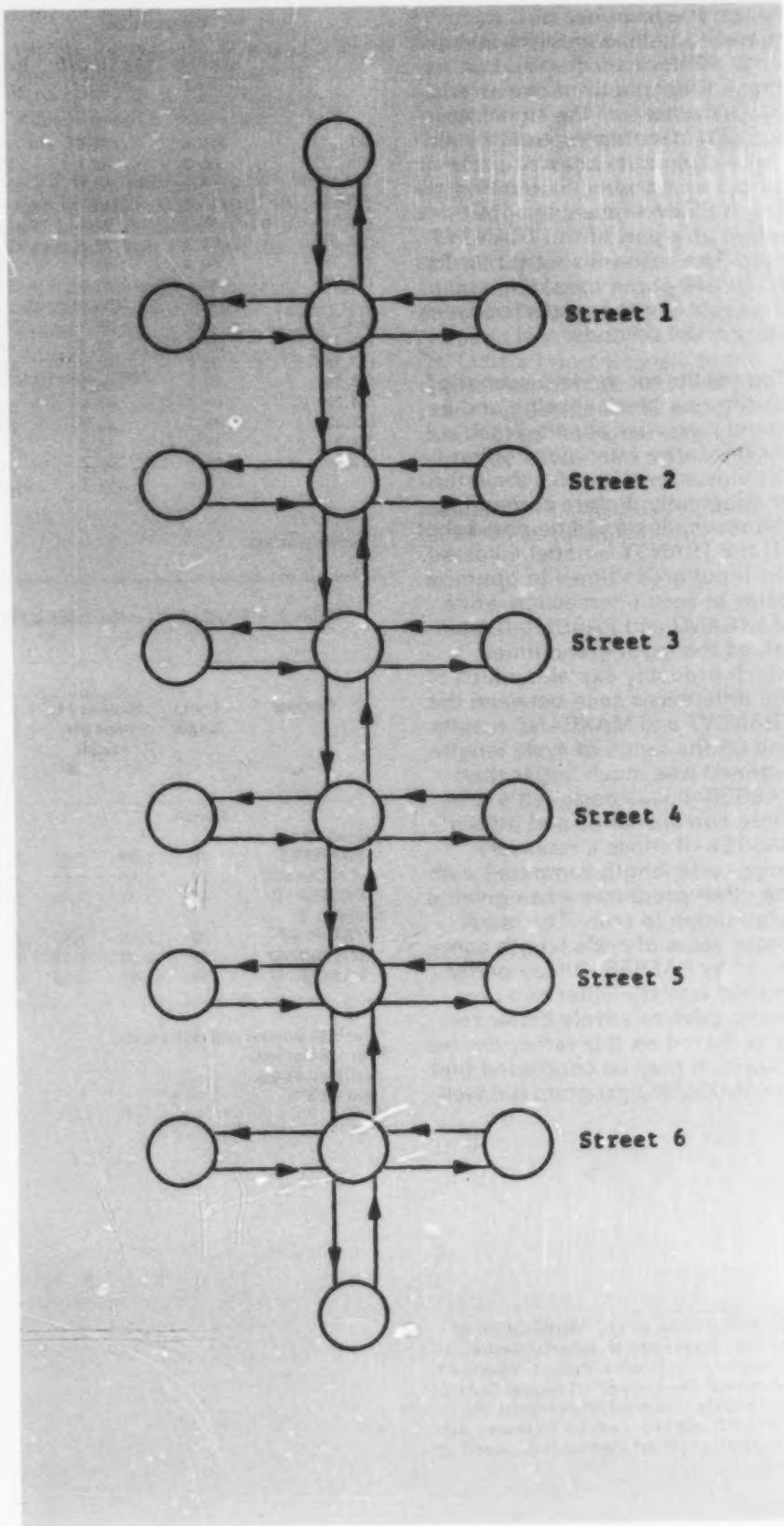
Two sets of integer variables are involved—the integers introduced through the first constraint and a set of two integers introduced at each intersection to represent each possible left turn phase sequence pattern. The variables in this latter set are restricted to values 0 or 1 so that there are four possible combinations—0–0, 1–0, 0–1, and 1–1— each of which represents one of the four possible phase patterns on the arterial at each intersection. Details of the mathematical formulation and solution process may be found in reference 5.

Comparison With Other Programs

At present, MAXBAND has been compared with other approaches in only two instances. The network shown in figure 1 consists of nine intersections on Wisconsin Avenue in Washington, D.C., between and including Hall and Porter Streets. A morning peak data set for this network was obtained from the District of Columbia Department of Transportation. MAXBAND was used to compute the offsets on the arterial, using the cycle length, green times, and phase sequences in existence when the data were collected. The resultant MAXBAND timing plan then was run on the NETSIM traffic simulation model and the results were compared with a NETSIM run of the existing timing plan. (*9*) The results for the measure of effectiveness of average speed, shown in table 1, indicate that the MAXBAND program improved the existing plan, especially in the southbound direction (equal weighting was assumed for the bandwidths in both directions).

Figure 2 shows an arterial that was used to compare the effectiveness of three programs—TRANSYT, PASSER–II, and

Figure 2.—Link-node diagram for test scenarios.



MAXBAND—for developing signal timing plans for arterial systems.[3] Scenarios were developed to test the response of the programs to independent variables such as block spacing and demand levels, both on the arterial and side streets. The signal timing parameters computed by all three programs included cycle length and offsets. In addition, green phase times were optimized as a part of the TRANSYT runs. The scenarios were restricted to two-phase operation and the cycle lengths ranged between 30 and 120 seconds.

The results for the two scenarios of differing block spacing and demand levels are shown in table 2 for the entire arterial including the side streets and for the arterial street only. Before comparing the results it should be noted that (1) the TRANSYT model adjusted the input green times to optimize delay at each intersection while MAXBAND and PASSER–II maintained the input green times, which probably explains much of the differences seen between the TRANSYT and MAXBAND results; and (2) the range of cycle lengths scanned was much larger than PASSER–II was designed for. In these two scenarios and others[4], PASSER–II chose a relatively large cycle length compared with the other programs when given a large range to scan. The much larger value of cycle length computed by PASSER–II may partly explain why the other two programs gave relatively better results. Based on this rather limited sample, it may be concluded that the MAXBAND program did well.

Table 1.—Simulation run using NETSIM to compare MAXBAND settings with existing settings on Wisconsin Avenue, Washington, D.C.

Link	Vehicle-miles		Vehicle-minutes		Average speed	
	Existing settings	MAXBAND settings	Existing settings	MAXBAND settings	Existing settings	MAXBAND settings
					Miles/hour	*Miles/hour*
(20,21)	110.6	111.0	303.1	300.6	21.90	22.40
(21,22)	46.2	46.4	197.8	181.1	14.00	15.40
(22,23)	62.9	63.8	254.2	224.1	14.90	17.10
(23,24)	114.7	115.1	637.1	518.1	10.80	13.30
(24,26)	37.2	37.7	185.0	155.2	12.00	14.60
(26,27)	75.2	78.5	207.0	208.9	21.80	22.50
(27,28)	60.4	61.7	211.5	191.2	17.10	19.40
(28,29)	88.1	91.8	297.7	302.9	17.80	18.20
∈	595.3	606.0	2,293.4	2,082.1	15.57	17.46
(29,28)	59.4	59.1	222.3	212.7	16.00	16.70
(28,27)	47.5	48.0	149.3	146.1	19.10	19.70
(27,26)	62.9	62.0	188.6	190.4	20.00	19.50
(26,24)	17.3	16.7	55.7	53.1	18.60	18.90
(24,23)	91.5	91.5	248.8	244.5	22.10	22.50
(23,22)	48.2	48.6	204.3	255.1	14.20	11.40
(22,21)	34.9	34.7	139.0	115.9	15.10	18.00
(21,20)	90.7	92.8	278.7	253.5	19.50	22.00
∈	452.4	453.4	1,486.7	1,472.3	18.25	18.47

1 mile = 1.61 km

Table 2.—Simulation comparisons of TRANSYT, MAXBAND, and PASSER–II

Program	Cycle length	Measures of effectiveness							
		Number of stops per vehicle		Delay per vehicle		Average speed		Fuel efficiency	
		A[1]	B[2]	A	B	A	B	A	B
	Seconds			*Seconds*		*Miles/hour*		*Miles/gallon*	
Scenario I									
TRANSYT	30	1.98	2.01	21.62	17.07	18.8	18.8	13.52	13.96
MAXBAND	51	1.89	1.67	24.39	14.20	17.9	19.3	13.16	14.26
PASSER–II	65	2.45	1.70	35.00	19.20	16.6	18.5	12.43	13.88
Scenario II									
TRANSYT	35	2.19	1.90	22.20	17.13	18.1	18.7	13.16	13.84
MAXBAND	33	2.53	1.49	26.39	13.61	17.5	19.5	12.97	14.25
PASSER–II	90	2.91	2.16	46.84	31.45	14.0	15.3	11.06	12.11

[1] For both arterial and side streets.
[2] For arterial only.
1 mile = 1.61 km
1 gal = 3.8 L

[3] W. K. Kittelson et al., "Application of Existing Strategies to Arterial Signal Control—First Interim Report, Volume 1: Functional Description of Signal Control Techniques," unpublished report No. FHWA/RD–80/110, *Federal Highway Administration*, Washington, D.C., April 1980.

[4] Ibid.

Availability

The MAXBAND program that is available from the Federal Highway Administration free of charge is operational on IBM or AMDAHL equipment and requires 294K bytes of core storage (overlaid). With minor program modifications, it could be operational on most other computers with equivalent capabilities. A source tape, including two sample data sets, and a three-volume set of reports, including a users manual, may be obtained by writing the Urban Traffic Management Division, Offices of Research, Development, and Technology, Federal Highway Administration, Washington, D.C. 20590.

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(*2*) R. D. Desrosiers and C. H. Leighty, "Traffic Flow Responses to Unannounced Increases in Progression Speeds of Signal Systems," *Public Roads*, vol. 34, No. 1, April 1966, pp. 1–4, 13–15.

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(*4*) J. D. C. Little, M. D. Kelson, and N. H. Gartner, "MAXBAND: A Program for Setting Signals on Arteries and Triangular Networks," Transportation Research Record 795, *Transportation Research Board*, Washington, D.C., 1981, pp. 40–46.

(*5*) J. T. Morgan and J. D. C. Little, "Synchronizing Traffic Signals for Maximum Bandwidth," Highway Research Record 118, *Highway Research Board*, Washington, D.C., 1966, pp. 24–47.

(*6*) F. V. Webster, "Traffic Signal Settings," Road Research Technical Paper No. 39, *Her Majesty's Stationery Office*, London, 1958.

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(*8*) J. D. C. Little, "The Synchronization of Traffic Signals by Mixed Integer Linear Programing," *Operations Research*, Vol. 14, 1966, pp. 568–594.

(*9*) "Traffic Network Analysis with NETSIM, A User Guide," Report No. FHWA–IP–80–3, *Federal Highway Administration*, Washington, D.C., January 1980.

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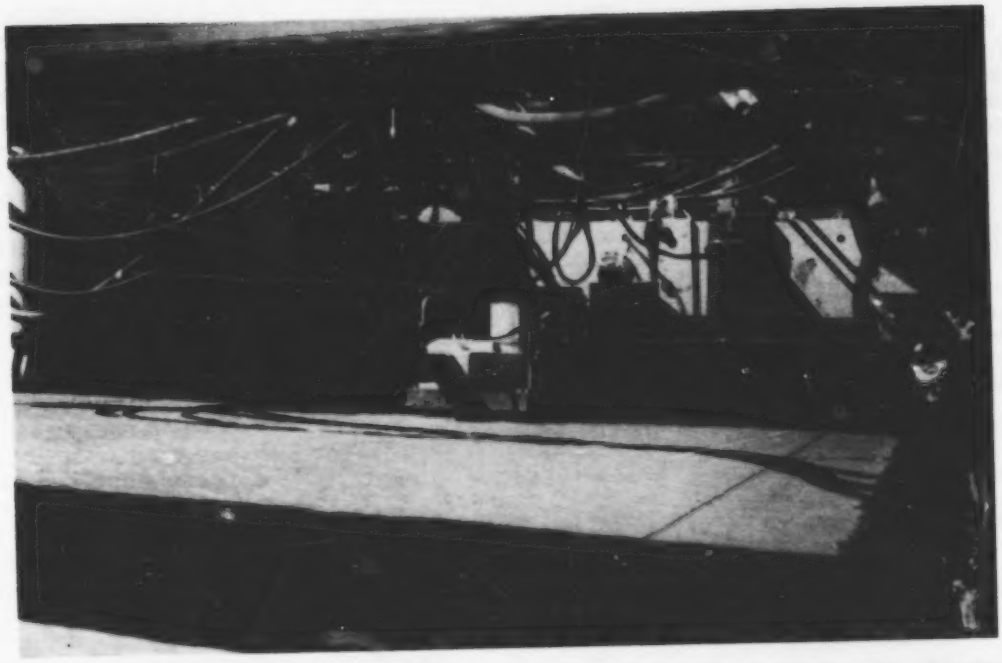
J. D. C. Little is Professor of Management Science at the Sloan School of Management, Massachusetts Institute of Technology. Dr. Little's interests include the application of mathematical programing techniques to the optimization of traffic signal settings. He currently is working on a project for FHWA to expand the capabilities of MAXBAND to include delay optimization.

Progress Report on the CMD: A Device for Continuous Monitoring of the Consolidation of Plastic Concrete

by
Terry M. Mitchell



Introduction

In the March 1979 issue of *Public Roads*, the Federal Highway Administration (FHWA), Office of Research, reported the development of a new device—the Consolidation Monitoring Device (CMD)—for monitoring the degree of consolidation of newly placed concrete. (*1*)[1] The CMD can be mounted on a slipform paver and will continuously and automatically monitor the degree of consolidation or densification of the concrete. The 1979 article included a discussion of the need for density monitoring, a description of the device's design and operation, and the results of initial laboratory and field evaluations.

Since 1979, development of the CMD has continued. Field trials completed by the Iowa and Illinois Departments of Transportation (DOT's) uncovered a problem with the original design, namely the sensitivity of the density reading to the device's height above the concrete pavement. Under FHWA contract the prototype CMD was modified to automatically correct the density reading for height changes. A simple capacitance distance gaging system that compensated for height changes was incorporated into the CMD and a second generation prototype CMD is now being constructed. This article summarizes the Iowa and Illinois field trials, development of the height compensation system, and future plans for the CMD.

The CMD

The CMD's source/sensor unit, shown schematically in figure 1, contains a 500 millicurie Cesium–137 (500 mCi ^{137}Cs) source and a radiation detector—a thallium-activated sodium iodide (NaI(Tl)) scintillation crystal and a photomultiplier tube. The amount of gamma radiation scattered by the concrete back into the detector is proportional to the density of the concrete. This same technique is already widely used by transportation agencies in commercially available, portable nuclear gages to control compaction of (1) soil and soil aggregate in pavement structures, (2) bituminous concrete pavements, and (3) portland cement concrete pavements and bridge decks.

[1] Italic numbers in parentheses identify references on page 72.

Figure 1.—Backscatter measurement with CMD source/sensor unit.

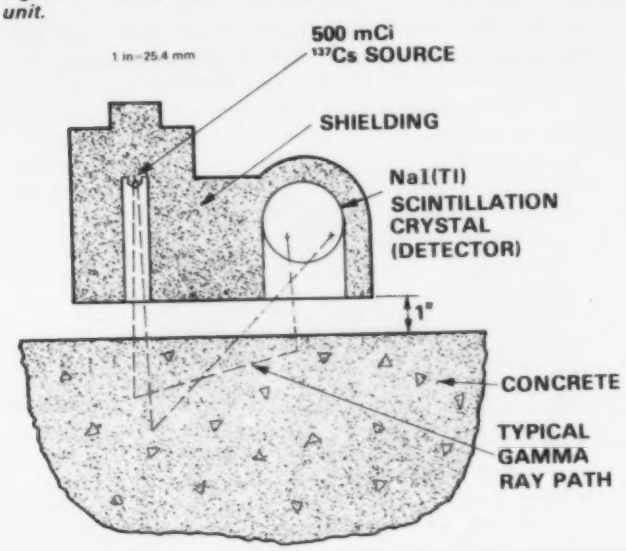


Figure 2.—Control and readout unit, original design.

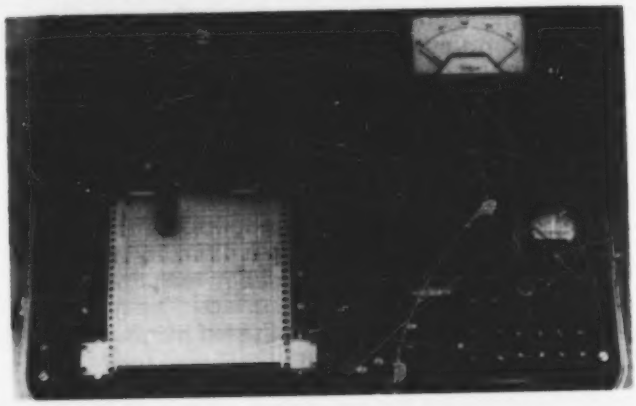
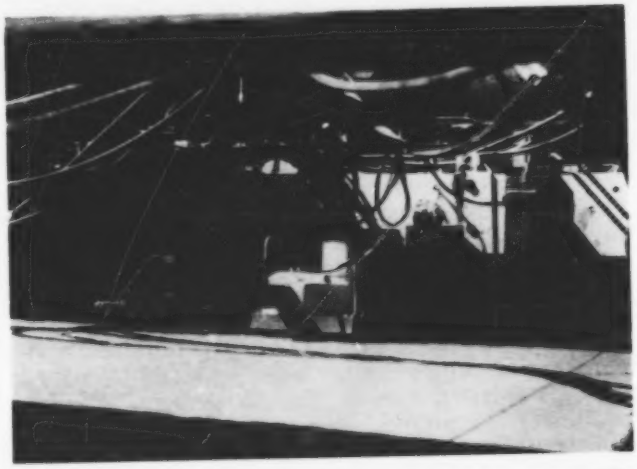


Figure 3.—Source/sensor unit and traversing mechanism.



The CMD's source/sensor unit is connected by a cable to its control and readout unit, located typically on the operator's deck of the slipform paver. The prototype CMD's control and readout unit (fig. 2) includes a meter display of concrete density, high and low density alarms, and a strip chart recorder to permanently record the density and the transverse and longitudinal positions of the source/sensor unit over the pavement surface. More detailed descriptions of the prototype CMD's design and operation are available in references 1–3.

The source/sensor unit is mounted and positioned on a slipform paver by a traversing mechanism (fig. 3). A carriage holds the source/sensor unit and supports it on wheels that roll on a horizontal guide beam. The guide beam is attached to the paver by three or more adjustable mounting mechanisms that enable vertical and angular positioning of the beam. The source/sensor unit of the original CMD had to be maintained at 25 ± 2 mm (1 ± 0.08 in) above the concrete surface to measure the density correctly. Although such a spacing is fairly easy to maintain on some slipform pavers, it is not possible, in practice, on others, as will be shown later in this article.

The CMD has a number of potential applications based on its ability to detect density irregularities while concrete is still plastic and before large volumes of defective concrete are in place. It can be used to detect malfunctions of individual vibrators on pavers, to evaluate the adequacy of vibrator spacings and operating frequencies, and to compare the effectiveness of external (pan) vibrators with that of groups of internal (spud) vibrators. It also has potential for detecting changes in the composition of concrete, particularly air contents well above or well below specified amounts. As a process control tool, it should enable contractors and State highway agencies to avoid multimillion dollar construction problems and lawsuits that can result from placing defective concrete. Finally, density control could become an integral part of a new quality assurance system that would allow agency acceptance of new concrete pavement at the time of construction, that is, without waiting for 28-day strength test results.

Field Trials

Although the original development contract for the CMD included an extensive field evaluation, additional field trials were conducted in 1978 under FHWA contract by the Iowa and Illinois Departments of Transportation. The purpose of the field trials was to determine the usefulness, fieldworthiness, and adequacy of the prototype CMD design. In each State, construction projects involving at least 8 lane km (5 lane miles) of paving were selected for the CMD trial. The Iowa researchers also planned a study to compare the effectiveness of internal and external vibrators.

After a 1-week laboratory familiarization study, the Iowa researchers began evaluating the CMD on an 11.9 km (7.4 mile) nonreinforced concrete pavement project on State highway 44, about 80 km (50 miles) west of Des Moines, Iowa. Although the slipform

paver used on this project was manufactured by the same firm as the one used in the original research, the configurations of the two pavers differed considerably around the extrusion meter. The extrusion meter support channel on this paver was too low to satisfactorily mount the CMD's guide beam. Angle-iron mounts had to be welded on the paver at several places before the mounting for the guide beam and traversing mechanism was satisfactory.

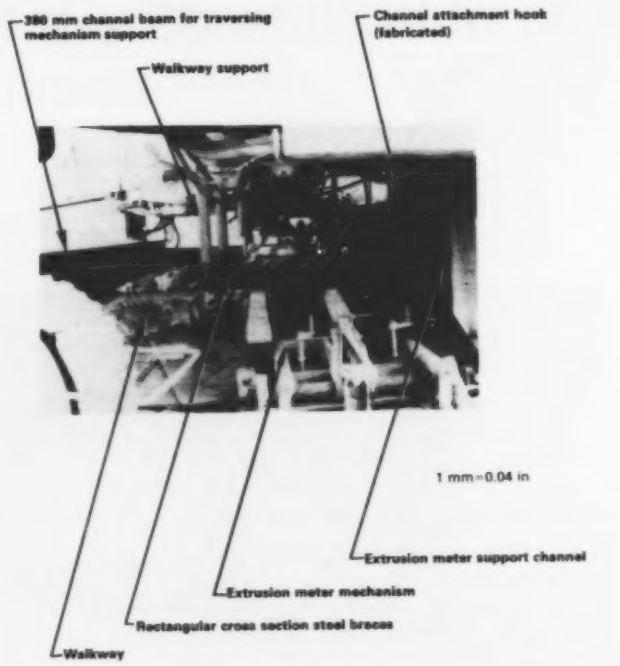
Because of the nature of the mounting, the researchers reported considerable difficulty in maintaining the 25 mm (1 in) air gap between the source/sensor unit and the concrete surface. The guide beam supports had to be readjusted as often as every 20 minutes. The gap variations also made it difficult to evaluate the device's accuracy and precision. (Iowa's data indicated that a 3 mm (0.12 in) change in the air gap would produce a 1 percent change in the density reading.) Other minor problems were spurious spikes in the strip chart density record (probably electrically caused) and the awkwardness of handling the heavy (80 kg [177 lb]) source/sensor unit in the field.

The vibrator comparison study showed that the external vibrator gave densities of 2 210 to 2 310 kg/m^3 (138 to 144 lb/ft^3) over the entire project. Mechanical problems with the internal vibrators severely limited their use during the project, and therefore a real comparison of the effectiveness of the two kinds of vibrators was not possible. The limited amount of data indicated that concrete densities obtained midway between the vibrators were typically 16 to 48 kg/m^3 (1 to 3 lb/ft^3) lower than the densities at the vibrators. The vibrators were spaced 460 to 760 mm (18 to 30 in) apart.

Because of the varying air gap problem, the Iowa researchers concluded that the CMD was not ready for general use. They recommended that the air gap be measured continuously and either the density reading be automatically corrected to compensate for changes in the gap or the air gap be maintained constant at 25 mm (1 in) by automatically moving the source/sensor unit up and down.

Following the Iowa study, the Illinois DOT conducted a field trial on a continuously reinforced concrete pavement project on U.S. 36 south and west of Jacksonville, Ill. The slipform paver used on this project was manufactured by another firm and differed considerably from the one used in the original research study. Mounting the CMD guide beam was even more difficult than on the Iowa project. Figure 4 shows a side view of the final mounting arrangement before the start of paving. The CMD's guide beam could not be mounted directly on the extrusion meter support channel because of the location of the extrusion meter itself and of a walkway across the back of the paver. Three rectangular steel braces were welded to an auxiliary 380 mm (15 in) channel beam. As shown in the figure, the braces were hooked over the extrusion meter support channel, and the CMD's guide beam was mounted on the auxiliary channel beam.

Figure 4.—CMD attachment to paver, Illinois field trial, side view.



Because of this mounting arrangement, the CMD's guide beam was located about 1.5 m (5 ft) back from the extrusion meter support channel and the CMD's ability to maintain the constant 25 mm (1 in) air gap above the concrete was reduced. Again air gap adjustments were necessary as often as every 20 minutes, and the Illinois researchers concluded that automatic compensation of the CMD's density reading for air gap changes was necessary.

The Illinois researchers also studied concrete densities obtained at and between internal vibrators. Their results were almost identical to those of the Iowa researchers. With a uniform spacing of 610 mm (24 in) between vibrators, they found that concrete densities midway between the vibrators typically were 16 to 48 kg/m^3 (1 to 3 lb/ft^3) lower than the densities at the vibrators. The researchers also used the CMD to determine when individual vibrators were functioning properly; several vibrators were replaced during the paving when malfunctions were indicated.

The Illinois researchers concluded that, with automatic compensation for the air gap changes, the CMD would have great potential for producing uniform consolidation in concrete pavement.

Air Gap Compensation

The Iowa and Illinois field trials confirmed that the CMD needed to be modified to compensate for the variations in the air gap. As the Iowa researchers had noted, there were two obvious options: (1) sense the gap size and modify the traversing mechanism to allow continuous vertical adjustment of the source/sensor unit to maintain the required 25 mm (1 in) gap, or (2) continuously sense the gap size and electronically correct the density value displayed on the readout unit to reflect the actual density—the density at a 25 mm (1 in) gap size. The first option was likely to make the traversing mechanism more complex as well as heavier; if a suitable gap sensor were available, the second option appeared much easier.

Therefore another FHWA contract study was undertaken to find a suitable gap measuring technique, develop a sensor, and modify the original readout unit to automatically compensate the density reading for the changes in the gap. The results of the study are summarized here and discussed in detail in reference 4.

The contract specification required that the modified CMD accurately monitor density while the air gap varied from 15 to 35 mm (0.6 to 1.4 in). Initial data indicated that the original CMD's density reading decreased by 6 kg/m³ per 1 mm (1.0 lb/ft³ per 0.1 in) increase in the air gap. The data also indicated a linear relationship between density reading and air gap over the 15 to 35 mm (0.6 to 1.4 in) range.

To monitor air gap size, the capacitance between a small, copper-sheet electrode mounted below the CMD's source/sensor unit and the concrete surface was measured. The measurement relies on the fact that capacitance is inversely proportional to the distance between the two plates of a parallel-plate capacitor. The capacitance is measured continuously by the circuit shown in figure 5. The concrete acts as the lower plate, a conductor at ground potential. The capacitor is alternately charged and discharged by the voltage-controlled switch; changes in the capacitance, caused by changes in the air gap, are reflected in the charge and discharge time of the capacitor between one-third and two-thirds of the supply voltage. The output of this circuit is an oscillating signal whose frequency, 30 to 37 kHz, varies with the capacitance value.

The capacitance probe consists of a 100 × 180 mm (4 × 7 in) copper sheet and an electrical guard plate, which are encapsulated in silicone rubber. The probe, which acts as the upper plate of the capacitor, is shown in figure 6, and in place on the CMD carriage in figure 7. As stated previously, the concrete acts as the lower plate of the capacitor. No grounding wire is necessary from the CMD because electrical continuity is achieved through the paving machine. Changes in the concrete mix do not affect the air gap measurement nor does the presence of a water film on the concrete surface.

Figure 5.—Capacitance measurement circuit.

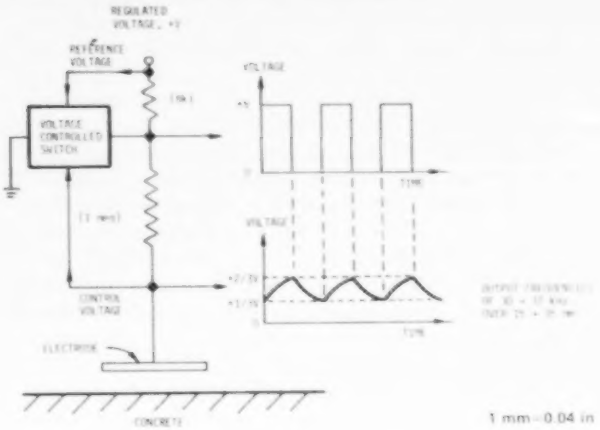


Figure 6.—Capacitance probe (shown with electrode facing up).

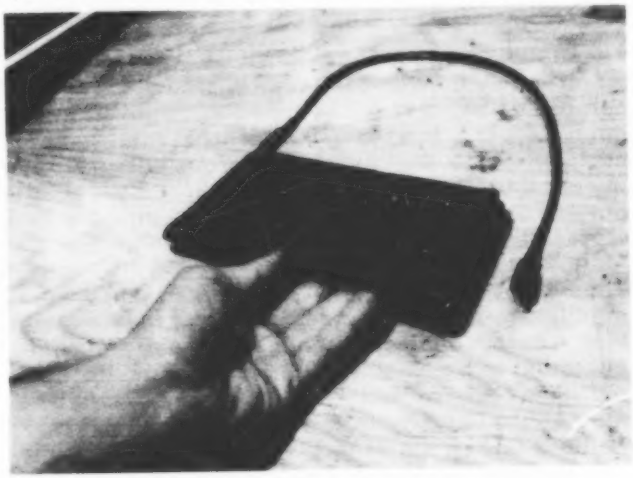


Figure 7.—Capacitance probe in place on carriage.

Integrating the capacitance probe compensation signal with the CMD's uncompensated density signal required additional electronic circuitry. The two signals had to be summed to produce a density signal that is not affected by changes in the size of the air gap (fig. 8). The 30 to 37 kHz output from the capacitance air gap measurement first passes through a frequency-to-voltage converter, which produces a direct current voltage proportional to the air gap size. Because the CMD's uncompensated density signal varies linearly with the air gap, the capacitance probe's output also had to be linearized as follows: As the capacitance probe output voltage passes preset electronic switch points, different resistors are introduced into the circuit to change the gain and raise the voltage to the linearized output line. Nine gain regimes are necessary to adequately simulate linearization. Figure 9 shows the original capacitance probe output voltage curve and the linearized output voltage, both plotted against air gap size.

The modifications to the original CMD's electronics were completed with the addition of temperature compensation, to keep the capacitance probe output constant over 5° to 45° C (41° to 113° F), and the circuitry to sum the capacitance probe and uncompensated CMD signals. A time constant also was applied to the air gap signal to match the time constant selected for the CMD density signal.

The display panel of the CMD's readout unit was modified to provide a meter display of the air gap size. A switch on the panel allowed the air gap compensation to be switched so that either the uncompensated or the compensated CMD density could be fed into the density meter and strip chart recorder. Connections on the panel also allowed both the air gap size and the uncompensated density to be transmitted to an auxiliary strip chart recorder external to the control and readout unit.

Laboratory evaluation

The effectiveness of this air gap compensation was examined in the laboratory using a variable height test stand. A hydraulic cylinder and hand pump were used to raise and lower the CMD's source/sensor unit over the specified 15 to 35 mm (0.6 to 1.4 in) air gap above a concrete sample. Figure 10 shows a strip chart record of the compensated and uncompensated density readings while the air gap was increased from 15 to 35 mm (0.6 to 1.4 in). The figure clearly shows that the density reading is automatically corrected to compensate for the changes in the air gap over the specified range.

Field test

The evaluation of the air gap compensation system was completed with a brief field test in August and September 1980 on a reinforced concrete pavement project on U.S. 219, about 50 km (30 miles) south of Buffalo, N.Y. The guide beam mounting area of the slipform paver (the extrusion meter area) differed

Figure 8.—Scheme for density compensation.

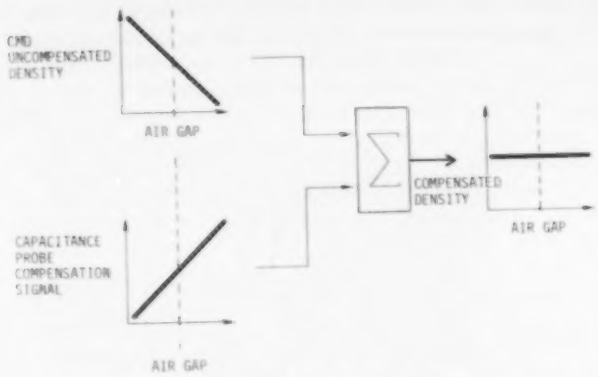


Figure 9.—Original and linearized output voltages as a function of air gap.

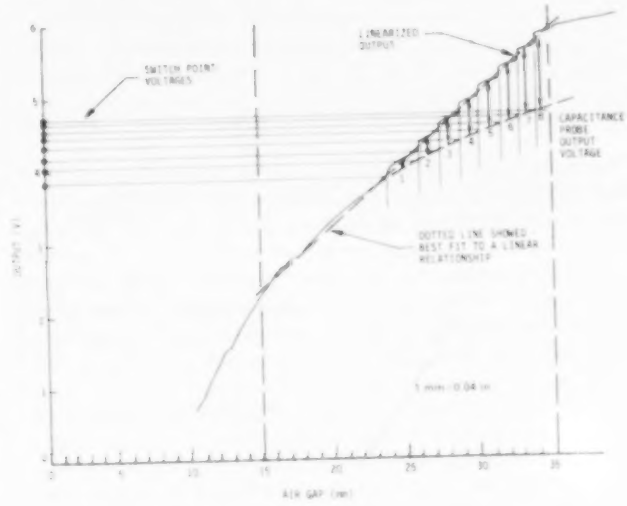
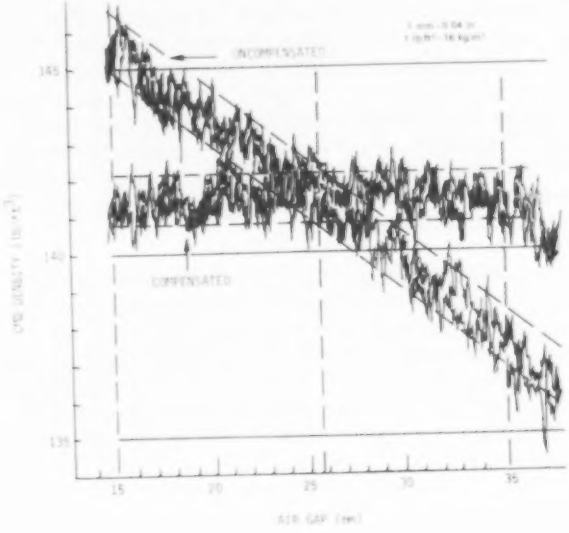

SWITCH POINT VOLTAGES
LINEARIZED OUTPUT
CAPACITANCE PROBE OUTPUT VOLTAGE
DOTTED LINE SHOWS BEST FIT TO A LINEAR RELATIONSHIP

Figure 10.—Comparison of compensated and uncompensated CMD densities as a function of air gap.



from the configuration in all three previous field trials, so again the researchers had installation problems. In this case, the mounting brackets were modified and part of a vertical I–beam on the paver was cut away to satisfactorily mount the guide beam.

No attempt was made during this trial to correlate the CMD density readings with results obtained by other conventional tests, for example, rodded unit weight, weighed density, and core density. Such correlations had been established in the original CMD development study. (*1, 2*) The present field trial was aimed at demonstrating the effectiveness of the air gap measurement and the compensation of the CMD density readout.

The data indicated that the air gap compensation worked well over the entire 15 to 35 mm (0.6 to 1.4 in) range and over the entire period of the field test. Both construction-produced variations in the air gap and intentional tilting of the guide beam were adequately compensated for in the CMD's density reading. Limited comparisons between the CMD readings and density readings by commercially available, static nuclear density gages showed good agreement.

The records of the air gap provided by the auxiliary recorder suggested another possible application of the capacitance probe. These plots showed a substantial increase in air gap, lasting approximately 0.3 m (1 ft), every 4.9 m (16 ft) of slipform paver travel. Because the CMD was rigidly attached to the paver's extrusion meter, such an increase corresponds to a slight depression in the concrete itself. Further investigation showed actual depressions in the concrete, typically 5 mm (0.2 in) deep and coinciding with the overlap of the steel wire reinforcing mesh embedded in the concrete (the mesh sections were 4.9 m [16 ft] long and overlapped by about 0.3 m [1 ft]). The researchers suggested that the depression might be caused by increased vibration and consolidation around the overlap.

The detection of the depressions at the mesh overlap points suggested that the capacitance probe might be useful for monitoring the smoothness of newly placed concrete pavement. Capacitance probes of the type used in the CMD would be very inexpensive. Assuming immediate feedback on pavement smoothness could be used by a contractor to improve control of the paver and finishing operations, a series of such probes with associated data processing electronics could be a very useful tool.

The CMD's Future

Early in 1981, the prototype CMD was returned to FHWA's Office of Research. Several instrumentation problems—breakdown of the strip chart recorder and the appearance of large spikes, apparently electrically generated, in the density readings—indicated that the first generation prototype was showing signs of age. Two major reworkings of the electronics since the initial fabrication had reduced the prototype's reliability. It was decided, therefore, to construct a second generation prototype with the following objectives:

- Improve the electronics by using the latest technology in established reliability electronic components.
- Replace obsolete major components such as the strip chart recorder.
- Redesign the panel of the control and readout unit to simplify standard operation and to make the CMD operable by inspector-level personnel.
- Redesign the guide beam to allow installation and full traverse on both 3.7 and 7.3 m (12 and 24 ft) wide slipform pavers. (The guide beam for the first generation prototype will operate only over the shorter distance.)

The construction of the second generation prototype is scheduled for completion during the spring of 1983. Field trials by State highway agencies will be scheduled for the 1983 construction season.

Two additional research studies have resulted from the CMD's successes and other construction control needs. In the first study a device for mounting on compaction rollers is being developed to monitor the density and temperature of asphalt concrete during compaction. Much of the nuclear and electronic technology used in the CMD will be used in designing the new device, although some changes will be required to allow the instrument to be used both on full-depth and thin (25 to 50 mm [1 to 2 in]) overlays. Infrared thermometry is the method of choice for the temperature measuring system.

This study includes development of a prototype device, laboratory evaluations, and field trials on three paving projects. The field trials will include comparisons of the new device's density data with densities obtained from cores and by static nuclear gages. The study is scheduled for completion late in 1982. Additional field trials by State highway agencies will be scheduled for the 1983 construction season.

The second study, scheduled to begin in the fall of 1982, will develop equipment for monitoring pavement surface smoothness during construction. Currently, surface smoothness measurements, for defining the rideability of new concrete pavement, are made on the hardened concrete. When rough areas are encountered, they must be ground down.

The grinding equipment is expensive to purchase ($150,000) and operate (perhaps $50,000 a year to maintain the diamond cutting edges), and grinding is very labor intensive. Therefore, development of a surface profilometer that would determine smoothness while the pavement surface is still workable is desirable. The accuracy and low cost of the capacitance probe developed for the air gap measurement in the CMD suggest capacitance to be a promising technique for a profilometer for plastic concrete. The research will include an examination of capacitance as well as acoustic, optical, and other promising techniques, followed by the development of a prototype profilometer.

Summary and Conclusions

Development has continued on the CMD, a nuclear backscatter device to continuously and automatically monitor the degree of consolidation of plastic concrete. Initial field evaluations by State highway agencies confirmed the device's potential as a quality control tool but indicated that additional equipment development was needed. The major design shortcoming, the sensitivity of the device's density reading to changes in the air gap between the device and the pavement, was effectively eliminated by adding a simple gap-measuring device and automatically compensating the density reading for air gap changes. A second generation CMD is currently under construction.

FHWA's Offices of Research, Development, and Technology believe the CMD offers highway agencies and contractors a valuable tool for controlling the quality of concrete pavement as it is being placed. The real test, however, is costs and benefits. For both contractors and State highway agencies, materials and construction defects can create million-dollar problems. Small investments in equipment, such as the CMD, for monitoring quality before kilometres (miles) of defective concrete are in place, quickly pay for themselves. Furthermore, better control of consolidation should increase average pavement life and stretch highway agencies' limited maintenance and reconstruction dollars.

REFERENCES[2]

(1) T. M. Mitchell, P. L. Lee, and G. J. Eggert, "The CMD: A Device for Continuous Monitoring of the Consolidation of Plastic Concrete," *Public Roads,* vol. 42, No. 4, March 1979, pp. 148–155.

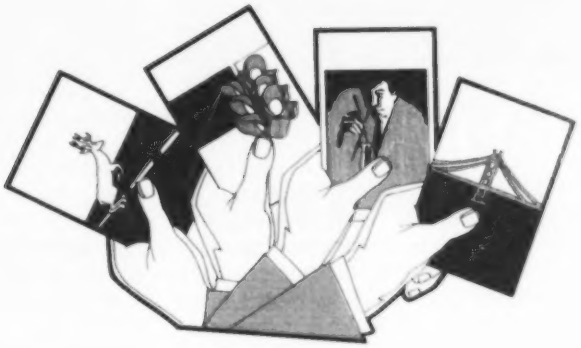
(2) P. L. Lee and G. J. Eggert, "Development of a Device for Continuous Automatic Monitoring of Consolidation of Fresh Concrete," Report No. FHWA–RD–78–27, *Federal Highway Administration,* Washington, D.C., March 1978. PB No. 285966.

(3) P. L. Lee and G. J. Eggert, "Instrument Manual for Prototype Concrete Consolidation Monitoring Device," Report No. FHWA–RD–78–96, *Federal Highway Administration,* Washington, D.C., May 1978. PB No. 290735.

(4) G. J. Kirby and R. W. Lusignea, "Improvement of Device (CMD) for Monitoring the Consolidation of Plastic Concrete," Report No. FHWA/RD–81/117, *Federal Highway Administration,* Washington, D.C., August 1981. PB No. 82 132390.

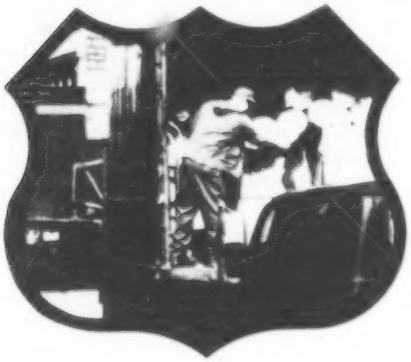
Terry M. Mitchell is a materials research engineer in the Construction, Maintenance, and Environmental Design Division, Office of Engineering and Highway Operations Research and Development, FHWA. Dr. Mitchell joined FHWA in 1971 and currently is the project manager for Projects 6F, "Develop Rapid and More Significant Test Procedures for Quality Assurance," and 6G, "Performance Related Specifications for Highway Construction and Rehabilitation," in the Federally Coordinated Program of Highway Research and Development.

[2]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.



Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Office of Engineering and Highway Operations Research and Development (R&D) and Office of Safety and Traffic Operations R&D. The reports are available from the address noted at the end of each description.

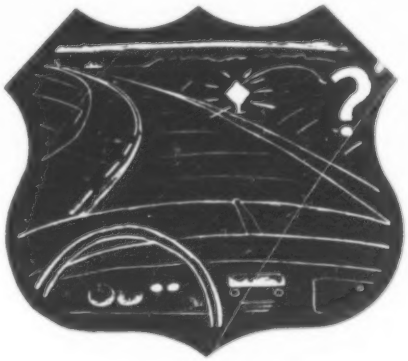


Curbside Pickup and Delivery Operations and Arterial Traffic Impacts, Report No. FHWA/RD–80/020

by FHWA Office of Safety and Traffic Operations R&D, Urban Traffic Management Division

This report presents an analysis of curbside pickups and deliveries (PUD's) of freight in urban areas. Data were collected in six cities on the characteristics of the PUD trip, the parking of the delivery vehicle, the kind and size of the business, and the impact of double parking on arterial traffic performance. These data were analyzed and tools were developed to predict PUD demand, parking patterns, and resultant traffic impact under various conditions. These tools were used to test various traffic engineering strategies to improve the level of service on arterials. The report recommends the most practical strategies for demonstration, including improved management of curbspace use, improved signing and striping, signal timing adjustments, and enforcement levels.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 225914).



Luminous Requirements for Traffic Signs, A Comparison of Sign Performance and Requirements, Report No. FHWA/RD–81/158

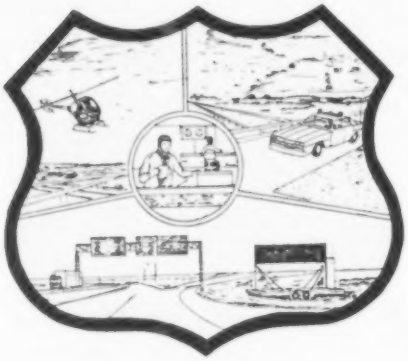
by FHWA Office of Safety and Traffic Operations R&D, Systems Technology Division

To be effective, a traffic sign must transmit information to an approaching driver in enough time for the driver to gather and process the information and react appropriately. This report presents the results of a study of 11 new retroreflective traffic control signs to determine driver detection and recognition/message comprehension distances at night. Environmental effects were minimized by restricting the study to straight roads with homogeneous, nondistracting sign surroundings. Detection and recognition distances

of the study subjects were compared with analytically determined detection and recognition distances. All signs were detected at the required distance, but some messages were not comprehended at the required distances.

Speed recommendations are not provided or evaluated in this report. Because of the many variables that influence sign visibility, a more detailed study is investigating sign retroreflective requirements under various conditions.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 176553).



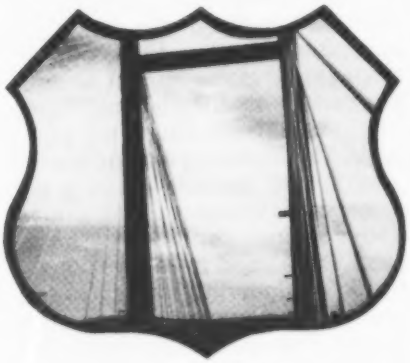
San Antonio Motorist Information and Diversion System, Report No. FHWA/RD–81/018

by FHWA Office of Safety and Traffic Operations R&D, Urban Traffic Management Division

This report documents a study to evaluate the effectiveness of a low-cost motorist information diversion system in San Antonio, Tex. The system was implemented in 1977 as a demonstration program to alleviate congestion and reduce accidents on I–35 in San Antonio near the central business district. As part of the program, I–35 traffic was rerouted around the business district and a low-cost changeable message sign system was used to divert freeway traffic and manage traffic during freeway maintenance.

The report also discusses the lessons learned from the demonstration program and provides recommendations for future urban motorist information diversion systems.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 131574).



Analytical Study for Fatigue of Highway Bridge Cables, Report No. FHWA/RD–81/090

by FHWA Office of Engineering and Highway Operations R&D, Structures Division

Designers of cable-stayed highway bridges must consider the significant resonant vibration motions that may be induced in individual cables at certain critical wind velocities. Such vibrations may result in an accumulation of bending stress cycles at the fixed ends of long, flexible cables sufficient to cause fatigue failures of component wires in the cables.

This report describes an analytical investigation of the complex fatigue crack initiation and propagation mechanism in small diameter, high-strength steel wires in large cables subject to wind-induced vibration. The bridge cable aerodynamic response formulas presented in the report provide the design engineer with methods for computing vibration frequencies, critical wind velocities, cable deflections, and cable bending stresses. Formulas are presented for the fatigue analysis of individual wires in a bridge cable based on a linear elastic fracture mechanics methodology. Guidelines are provided for estimating the fatigue life of the cable, and example calculations are shown for stay cables of an existing highway bridge.

The report also includes a discussion on the fatigue testing of wires and cables and an outline of recommended additional analytical and experimental research on the subject.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 245672).

Flexible Pavement Overlay Design Procedures, Volume 1 (Report No. FHWA/RD–81/032) and Volume 2 (Report No. FHWA/RD–81/033)

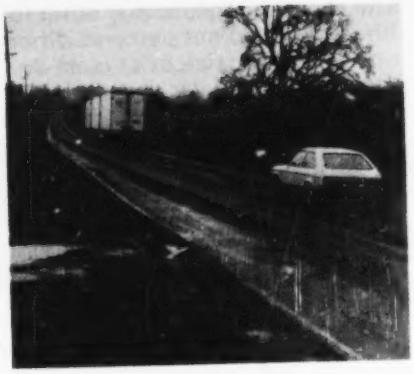
by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

These reports provide rational procedures based on elastic layer theory for designing flexible overlays for existing flexible pavements. The design procedures and analytical techniques presented predict the structural fatigue of flexible overlays from various geometric, material, loading, and environmental conditions.

Volume 1, **Evaluation and Modification of the Design Methods,** describes the development of new computerized design procedures based on a combination and modification of several existing flexible pavement overlay design methods. The new procedures incorporate the latest developments in flexible pavement evaluation and overlay design. Overlay thickness is determined by a fatigue distress function derived from American Association of State Highway Officials Road Test data. The required inputs for the new overlay design procedures include pavement dynamic deflection measurements; limited pavement crack survey data; projected traffic in terms of equivalent 80 kN (18 kip) axle loads; and material characterization (measured layer thicknesses and estimates of (1) Poisson's ratio for each layer, (2) the stress dependency relationship of base and subgrade moduli, and (3) the asphalt modulus-temperature relationship). Guidelines are presented for quantifying these parameters in the absence of laboratory test data. Environmental factors are provided for adjusting deflection measurements made at various times of the year.

Volume 2, **User Manual,** presents detailed instructions for obtaining the necessary input data and for entering the data into the computerized design program. Comparisons between the new design procedures and other overlay design methods presently used by three States show that the new procedures can be more economical because pavement evaluations and overlay thickness designs are made for each location where dynamic deflection measurements are taken. This permits the design engineer to consider alternate, more cost-effective remedial strategies, such as improved drainage, recycling, or reconstruction, where very thick overlays would otherwise be required.

The reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 82 136672 and 82 136680).



The Effect of Truck Size on Driver Behavior, Report No. FHWA/RD–81/170

by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

The increased size and weight limits for trucks today have raised several safety issues, including possible handling and braking problems, performance on grades, traffic impedance, and sign blockage. However, the effect of these larger trucks on the drivers of adjacent vehicles has not been widely discussed or studied.

This report discusses the effect of truck size on the behavior of drivers who interact with trucks in selected roadway situations. Truck length/configuration was studied in freeway entrance merge, mainline lane change, and narrow bridge situations, while truck width was studied in a rural two-lane, two-way passing situation. Microscopic traffic measures were collected and erratic maneuvers and truck type were observed for the length/configuration studies. In the truck width passing study, an impedance factor was used to induce passing of an experimentally widened vehicle.

The report suggests that automobile drivers do not perceive differences in truck size or at least do not react unusually to these differences.

Limited copies of the report are available from the Safety and Design Division, Office of Safety and Traffic Operations Research and Development, Federal Highway Administration, Washington, D.C. 20590.

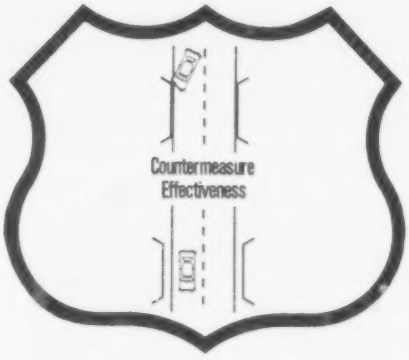
Model System for Evaluating Safety Projects Using State Record Systems, Report No. FHWA/RD–81/186

by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

This report presents the results of a study on the adequacy of existing recordkeeping systems for evaluating highway safety programs. The kinds of highway safety-related data collected by States are presented in the report as are the methods used to collect and store the data.

A model system developed under this study to store, maintain, and retrieve safety data and evaluations of projects is described in the report. The model system addresses the problem of matching hazardous sites with similar sites where safety projects have been implemented and evaluated. Also, the model system can perform project evaluations using existing recordkeeping systems of States.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 202516).



Estimating the Safety Benefits for Alternative Highway and/or Operational Improvements, Volume I—Research Summary, Report No. FHWA/RD–81/179

by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

This report presents the results of a study to evaluate the safety of various highway design improvements and to develop techniques for predicting accident frequency and severity. A total of 326 test and control sites in Alabama were studied to determine the effect of 14 different safety improvements. Parametric and nonparametric statistical tests were used to estimate accident frequency and severity reduction so that safety improvement funds could be allocated more accurately. The ratio of property damage only accidents to total accidents—the severity ratio—was used to estimate severity reduction. Generally, the confidence intervals for these estimates were quite wide. A dynamic programing procedure was developed to translate the estimates into budget allocation policy.

Limited copies of the report are available from the Safety and Design Division, Office of Safety and Traffic Operations Research and Development, Federal Highway Administration, Washington, D.C. 20590.

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items that have been recently completed by State and Federal highway units in cooperation with the Office of Implementation, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies.

U.S. Department of Transportation
Federal Highway Administration
Office of Implementation
Washington, D.C. 20590

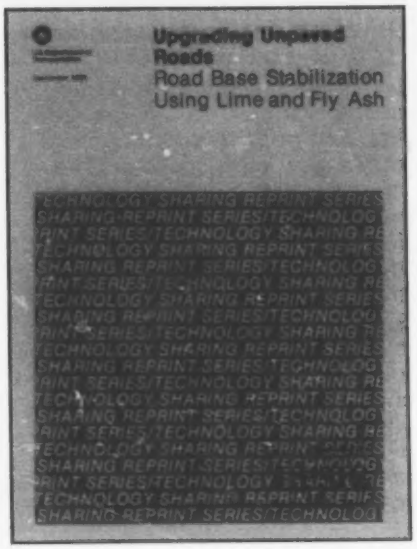
Items available from the Office of Implementation can be obtained by including a self-addressed mailing label with the request.

Upgrading Unpaved Roads—Road Base Stabilization Using Lime and Fly Ash

by Upper Plains States Innovation Group

In the United States, over 70 percent of the total road kilometres (miles) are unpaved. Most of these roads are under the jurisdiction of county and other local governments. As maintenance and construction needs continue to increase, local highway agencies are searching for new ways to improve the serviceability of unpaved roads and to decrease construction and maintenance costs.

Stabilization, particularly lime-fly ash-aggregate (LFA) stabilization, has proven to be a cost-effective



method for upgrading unpaved roads and improving performance and serviceability. This report is intended to help practicing road superintendents determine whether LFA base stabilization with an asphaltic surface seal is a cost-effective approach for upgrading local unpaved roads.

Limited copies of the report are available from the U.S. Department of Transportation, Technology Sharing Office (I–40), Washington, D.C. 20590.

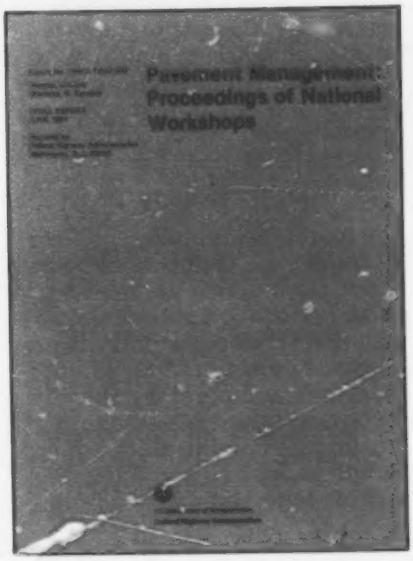
Roadway Delineation Practices Handbook, Implementation Package 81–5

by Office of Implementation

This handbook provides practical guidelines for the proper application of available delineation systems. Although the handbook is not intended to be a state-of-the-art report, it does provide an overview of current developments in roadway delineation techniques. Current and newly developed devices, materials, and installation equipment are discussed in terms of demonstrated or anticipated performance based on actual experience or field/laboratory tests.

The handbook is intended primarily for design, traffic, and maintenance engineering personnel. The uses, materials, application procedures, service life, and maintenance of painted markings, thermoplastic and other durable markings, raised pavement markers, and post delineators are presented as well as administrative and management considerations.

Copies of the handbook may be purchased for $4 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00198–5).



Pavement Management: Proceedings of National Workshops, Report No. FHWA–TS–82–203

by Office of Implementation

Two national workshops on pavement management were conducted by the Transportation Research Board for the Federal Highway Administration. The workshops addressed pavement management processes including information acquisition and processing, planning and programing, design, construction, maintenance, rehabilitation, and field monitoring.

This report contains the proceedings of both workshops and provides valuable information for improving the pavement management practices of an organization, particularly for developing and implementing a pavement management subsystem to improve the scheduling of maintenance and rehabilitation projects. Highlights and major recommendations of the two workshops are provided. Pavement management considerations, definitions, benefits, and implementation procedures also are discussed. The need to make better pavement management decisions, provide feedback on the consequences of those decisions, consider alternative practices, and strive for consistent decisions at different levels within an organization using objective criteria were emphasized at the workshops.

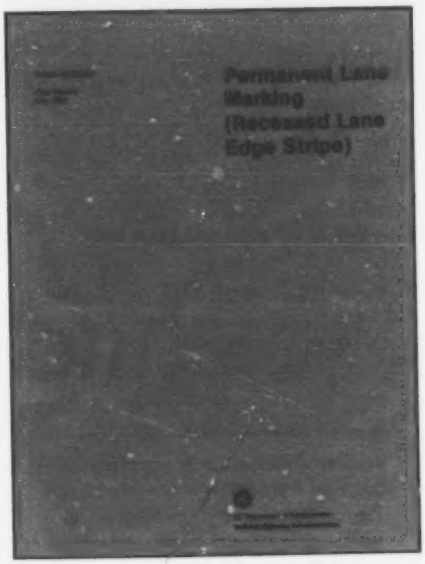
Limited copies of the report are available from the Office of Implementation.

Permanent Lane Marking (Recessed Lane Edge Stripe), Report No. FHWA–TS–82–204

by Office of Implementation

Maintaining adequate roadway delineation on mountain passes during winter is a continual problem because conventional traffic paint cannot withstand sanding operations, studded tires, chains, and snowplowing. This report summarizes a study to evaluate different methods of cutting recessed skip-stripe grooves and various pavement marking materials placed into the recesses to find a permanent marking system.

Only one method of grooving was found that produced the desired recess shape at a reasonable cost. All three of the marking materials survived for 3 years, but none produced the desired wet-day or wet-night visibility needed for adequate lane delineation.



The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 105446).

Functional Requirements of Highway Safety Features, Report No. FHWA–TS–81–216

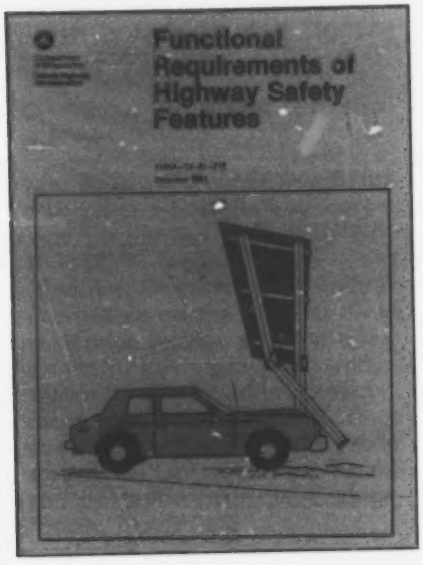
by Office of Implementation

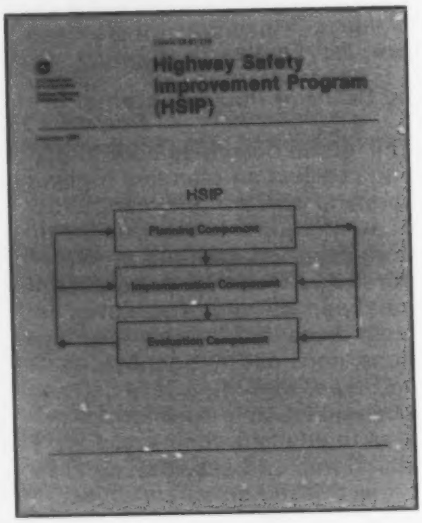
In 1978 FHWA conducted a nationwide safety review to determine the degree to which design and construction of highways and highway safety upgrading projects adhered to the principles in the American Association of State Highway and Transportation Officials' report *Highway Design and Operational Practices Related to Highway Safety* (Yellow Book). During the review, operational and maintenance practices on all kinds of highways were observed. Because it was found that the purposes and performance requirements of highway safety features

were not understood clearly, this training notebook was developed for construction and maintenance personnel.

The notebook describes how various highway safety features work and why they are used, identifies the factors that will adversely affect the intended performance of each feature, and illustrates, through examples of good and bad installations, what field personnel should look for to identify safety problems in the field installations.

Copies of the notebook may be purchased for $7.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00237–0).





Highway Safety Improvement Program (HSIP), Report No. FHWA–TS–81–218

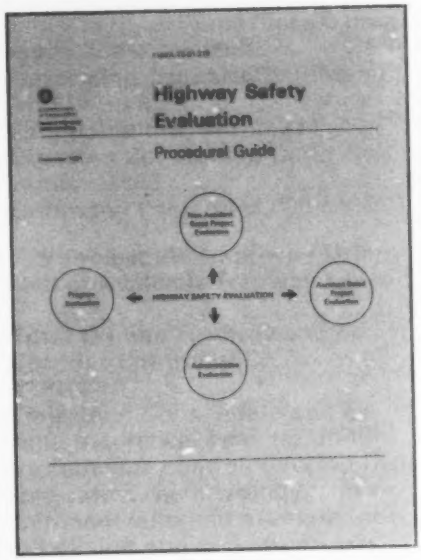
by Office of Implementation

This manual provides State and local highway agencies guidelines for developing and implementing a highway safety improvement program that best meets their capabilities and needs. The manual describes how to plan, implement, and evaluate a highway safety improvement program that complies with *Federal-Aid Highway Program Manual 8–2–3*; select the most appropriate procedures based on an agency's objectives, resources, and highway system; and use current information on reporting requirements, funding sources, and practices of other highway agencies.

Copies of the manual may be purchased for $7.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00241–8).

Highway Safety Evaluation, Procedural Guide, Report No. FHWA–TS–81–219

by Office of Implementation



This guide describes procedures for evaluating highway safety programs and projects. The guide describes how to select appropriate measures of effectiveness and efficiency for evaluating safety improvements using either accident data or alternate measures of hazard reduction; evaluate safety improvements and use the results to recommend improvements for other safety problems; organize and manage evaluation

processes for providing feedback on the effectiveness of safety projects to the planning and implementation components of the safety program; and perform program effectiveness and administrative evaluations.

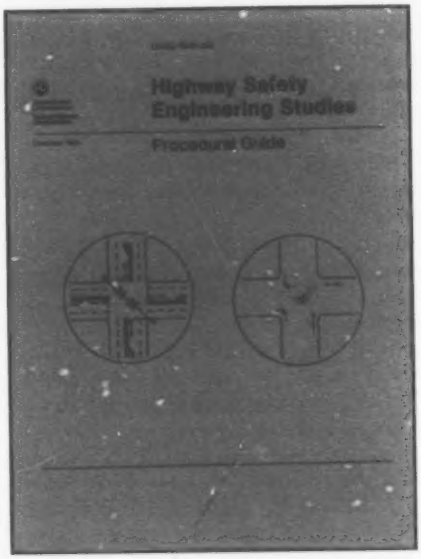
Copies of the procedural guide may be purchased for $9.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00242–6).

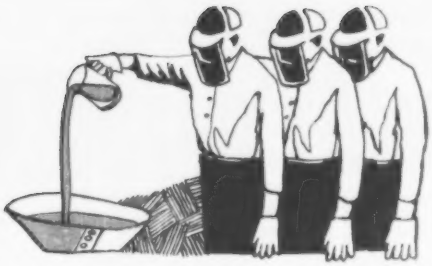
Highway Safety Engineering Studies, Procedural Guide, Report No. FHWA–TS–81–220

by Office of Implementation

This guide describes how to plan and conduct an effective highway safety engineering investigation of an identified hazardous location, using appropriate procedures and techniques; select the most appropriate procedures and techniques required for investigations, considering agency size and type; identify safety deficiencies and feasible countermeasures to alleviate the hazardous situations; and select a safety project based on safety objectives.

Copies of the procedural guide may be purchased for $11 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00240–0).





New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research, Development, and Technology. Space limitation precludes publishing a complete list. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R)—Performing State Highway or Transportation Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1P: Visual Guidance for Night Driving

Title: Study of Procedures Related to Efficiency of Raised Pavement Marker Systems. (FCP No. 41P3112)
Objective: Develop quantitative information on the interaction of the service lives, costs, installation techniques, roadway environments, and accident prevention potentials of raised pavement markers used in Texas.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1984
Estimated Cost: $160,000 (HP&R)

FCP Category 2—Reduce Congestion and Improve Energy Efficiency

FCP Project 2K: Metropolitan Multimodal Traffic Management

Title: Improving Traffic Signal Timings. (FCP No. 42K2162)
Objective: Develop procedures for improving signal timing plans and conduct field studies to evaluate the consequences of improved signal timing.
Performing Organization: University of California, Berkeley, Calif. 94720
Funding Agency: California Department of Transportation
Expected Completion Date: February 1984
Estimated Cost: $137,000 (HP&R)

Title: Fuel Consumption and Emission Values for Traffic Models. (FCP No. 32K2211)
Objective: Measure fuel consumption and emissions for the full range of vehicle performance capabilities of vehicles representative of the U.S. automobile fleet from 1979 to 1985. Convert these measurements into tables and equations for incorporation into various traffic models.
Performing Organization: Oak Ridge National Laboratory, Oak Ridge, Tenn. 37830
Expected Completion Date: January 1984
Estimated Cost: $279,000 (FHWA Administrative Contract)

FCP Project 2L: Detection and Communications for Traffic Systems

Title: Visual Incident Detection Evaluation Operation (VIDEO). (FCP No. 42L1042)
Objective: Develop the image transmission phase of the SCAN project and extend its concept to cover permanent station location within a system concept. Test the field applicability of television surveillance using low-frame rate samples of real-time images processed at the roadside.
Performing Organization: Maryland Department of Transportation, Baltimore, Md. 21211
Expected Completion Date: November 1983
Estimated Cost: $443,000 (HP&R)

FCP Project 2P: Improved Utilization of Available Freeway Lanes

Title: On-line Freeway and Street Corridor Control. (FCP No. 42P4074)
Objective: Consolidate and extend theoretical base for on-line systemwide control, develop field evaluation methodology, and experiment with and evaluate most promising on-line systemwide control scheme.
Performing Organization: University of California, Berkeley, Calif. 94720
Funding Agency: California Department of Transportation
Expected Completion Date: December 1983
Estimated Cost: $178,500 (HP&R)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4D: Remedial Treatment of Soil Materials for Earth Structures and Foundations

Title: Performance of Three Bridges in Permafrost Areas. (FCP No. 44D4104)
Objective: Evaluate the design and performance of three bridges in the permafrost areas of central Alaska.
Performing Organization: Cold Regions Research and Engineering Laboratory, Juneau, Alaska 99801
Funding Agency: Alaska Department of Transportation and Public Facilities
Expected Completion Date: September 1983
Estimated Cost: $16,000 (HP&R)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5H: Protection of the Highway System From Hazards Attributed to Flooding

Title: Evaluation of Design Practices for Riprap Used in Protection of Highway Crossings. (FCP No. 35H1212)
Objective: Determine by field evaluation and collection of hydraulic data the applicability of available riprap design procedures and provide guidelines for comprehensive design methods.
Performing Organization: U.S. Geological Survey, Reston, Va. 22092
Expected Completion Date: April 1985
Estimated Cost: $340,000 (FHWA Administrative Contract)

FCP Project 5L: Safe Life Design for Bridges

Title: Characterization of Acoustic Emission Signals. (FCP No. 35L2102)
Objective: Identify and characterize acoustic emission signals. Gather and evaluate laboratory test data on typical bridge steel specimens and components of bridge field tests. Develop acoustic emission systems and sensing elements for analyzing the acoustic emission signal needed to identify the acoustic emission source mechanism.
Performing Organization: United Technologies Research Center, East Hartford, Conn. 06108
Expected Completion Date: January 1984
Estimated Cost: $138,700 (FHWA Administrative Contract)

Title: Application of Bridge Formula to Truck Weight Enforcement. (FCP No. 35L3022)
Objective: Develop a simple, economical, and practical method of applying the bridge formula at weigh stations for truck weight enforcement. Prepare a users manual to include step-by-step procedures for weigh station operators using portable scales as well as platform scales.
Performing Organization: Chi Associates, Inc., Arlington, Va. 22201
Expected Completion Date: August 1983
Estimated Cost: $88,000 (FHWA Administrative Contract)

FCP Category 6—Improved Technology for Highway Construction

FCP Project 6D: Structural Rehabilitation of Pavement Systems

Title: Evaluation of Subsurface Road Drainage Systems. (FCP No. 46D3424)
Objective: Evaluate the performance of experimental pavement sections having an incorporated drainage layer and compare with that of conventional dense-graded pavement designs.
Performing Organization: New Jersey Department of Transportation, Trenton, N.J. 08628
Expected Completion Date: March 1987
Estimated Cost: $103,000 (HP&R)

FCP Category 0—Other New Studies

Title: Evaluation of Experimental Test Sections. (FCP No. 40M3013)
Objective: Validate the use of high-pressure liquid chromatography for asphalt analysis to predict the serviceability and longevity of pavements.
Performing Organization: Montana State University, Bozeman, Mont. 59717
Funding Agency: Montana Department of Highways
Expected Completion Date: September 1988
Estimated Cost: $63,000 (HP&R)

Title: An Evaluation of Epoxo 300–C Nonskid Coating for Use on Bridge Decks. (FCP No. 40M5784)
Objective:Test effectiveness and durability of Epoxo 300–C, a two-part epoxy nonskid coating, on steel grid, steel plate, and portland cement concrete sections of a bridge deck.
Performing Organization: Mississippi State Highway Department, Jackson, Miss. 39205
Expected Completion Date: May 1984
Estimated Cost: $17,000 (HP&R)

Title: Specially Constructed Bridges. (FCP No. 40M5794)
Objective: Evaluate bridge deck materials (watertight bridge expansion joints, waterproofing membranes, and treated structural and reinforcement steel) and construction practices that protect against premature deterioration. Perform surveys of techniques implemented by the Kentucky Department of Transportation.
Performing Organization: University of Kentucky, Lexington, Ky. 40506
Funding Agency: Kentucky Department of Transportation
Expected Completion Date: January 1987
Estimated Cost: $281,000 (HP&R)

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Recent issues of the magazine should be reviewed for kind of articles, style, illustrations, tables, references, and footnotes. *Public Roads* follows the U.S. Government Printing Office Style Manual.

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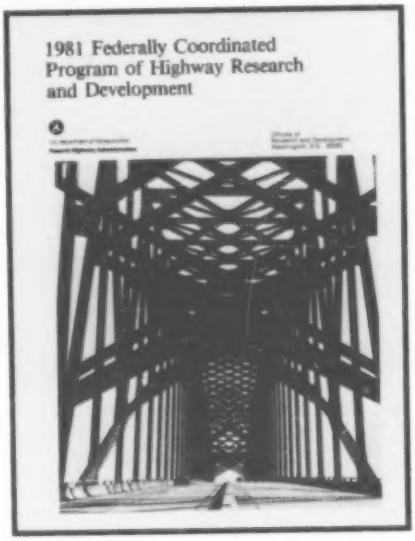
New Publication

The Offices of Research, Development, and Technology (RD&T), Federal Highway Administration (FHWA), have released their fiscal year **1981 Annual Report on the Federally Coordinated Program (FCP) of Highway Research and Development.**

The 36-page report briefly describes the goals and programs of the FCP and FCP accomplishments in highway research and development during FY 1981. Specific accomplishments in safety research, traffic operations research, environmental research, materials research, structural research, highway construction, and highway maintenance are cited. The report is prefaced by a message from Federal Highway Administrator R. A. Barnhart.



While supplies last, individual copies of the report are available without charge to highway-related agencies and universities. Requests should be sent on agency or institution letterhead to the Federal Highway Administration, Offices of Research, Development, and Technology, Operations Staff, Washington, D.C. 20590. Copies of the report are on sale for $4.75 by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00457–1).

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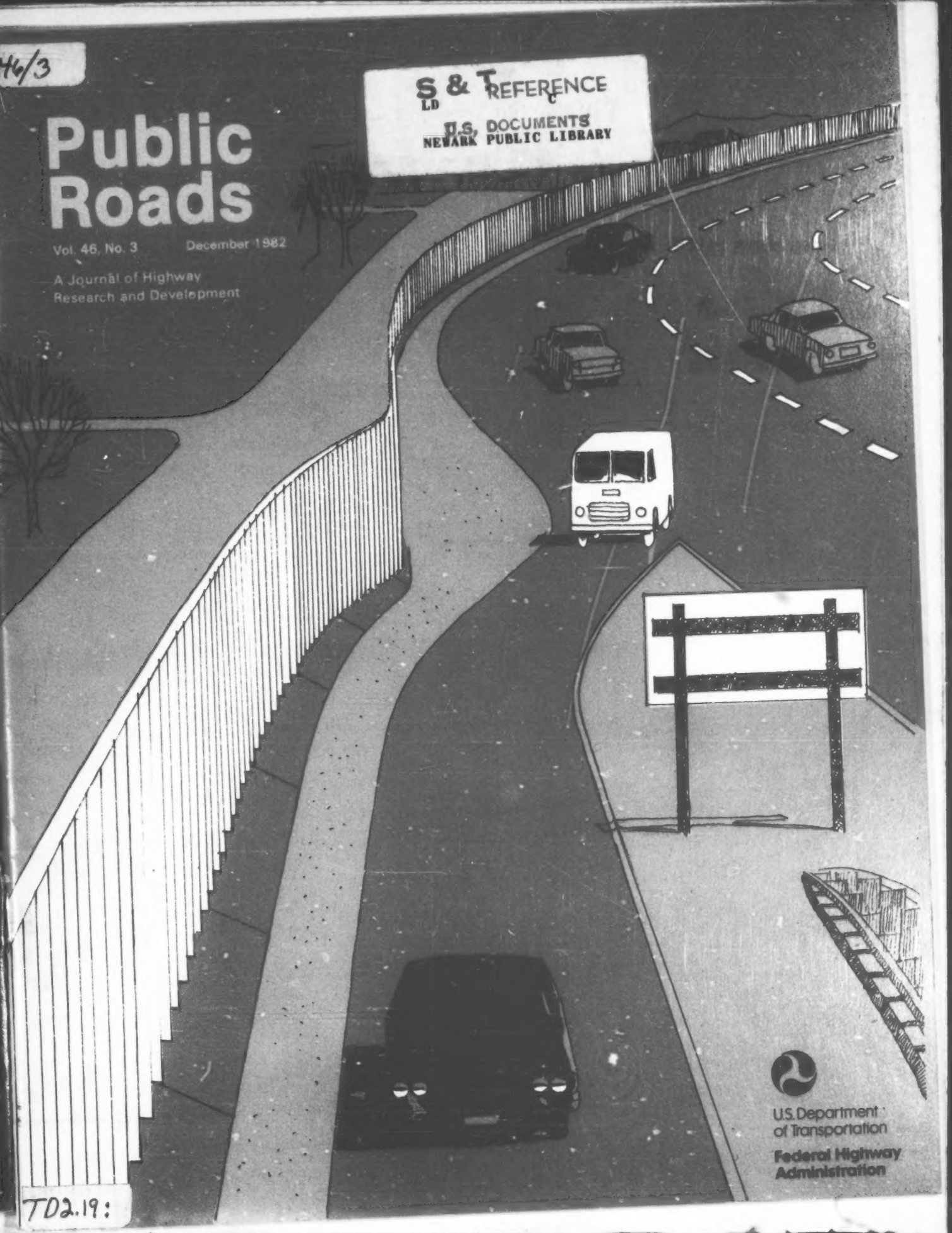

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The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through March 31, 1985.

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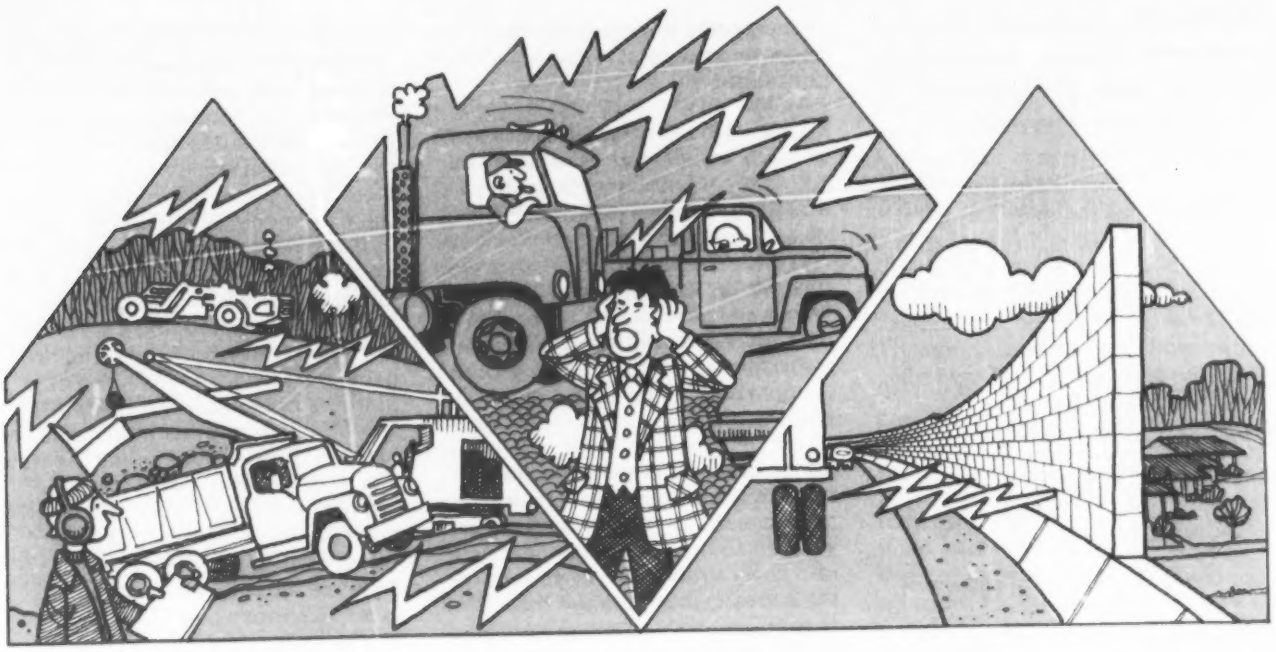


Prediction Modeling for the Assessment and Abatement of Highway Traffic and Construction Noise

by
Fred M. Romano

Environmental assessments of highway related noise are based on analytic prediction models. Because the application of current noise models is limited to freely flowing traffic and simple site characteristics, FHWA is developing refined noise models that will have application to a greater variety of highway noise assessments that must be performed. Noise models have been designed to assess noise propagation over asymmetric barriers and nonuniform ground cover, noise generated by stop-and-go traffic in urban settings, and construction noise impacts.

Computer versions, capable of predicting the energy-averaged equivalent sound level, L_{EQ}, have been prepared for each model and are undergoing test and evaluation.

Introduction

The Federal Highway Administration (FHWA) is committed to providing accurate traffic noise prediction models so traffic noise impacts may be anticipated and, when necessary, appropriate steps taken to minimize such impacts. Current traffic noise prediction models are accurate only in the average sense, and generally their application is limited to freely flowing traffic. Consequently, discrepancies between predicted and measured noise levels at particular sites may be unacceptably large, especially if noise barriers are present.

Examinations of current modeling practices have revealed three areas of noise assessment for which discrepancies may be removed and limitations overcome:

- Propagation of traffic noise over barriers and nonuniform absorptive terrain.
- Propagation of stop-and-go traffic noise in urban settings.
- Prediction of highway construction noise.

To remove deficiencies in these areas, three new and more accurate prediction models have been developed. Computer versions of these models are undergoing test and evaluation by FHWA. The first model predicts the propagation of noise from freely flowing traffic over nonuniform terrain. The second model is an analytic procedure developed to predict the generation and propagation of stop-and-go traffic in an urban setting. The third prediction model is concerned with the analysis and abatement of highway construction noise.

reflection coefficient, and the scattering coefficient may be specified for each approach separately.

4. The spacing and lateral distance of the receptor locations can be specified for each approach separately.

The model is restricted to the intersection of two streets at right angles, and to continuous or averaged building fronts where buildings are present. Traffic flow data used in the urban traffic noise prediction procedure are acquired through a modified version of the Network Flow Simulation Model (NETSIM). (*6*) The modified program generates traffic flow data as a function of time for a single intersection.

Contributions to receiver noise levels

Any vehicle passing through the intersection area can contribute to the noise at an arbitrary receptor location by one or more of the following mechanisms, in order of importance:

- Direct radiation.
- Simple reflection from one or more surfaces.
- Multiple reflection.
- Diffusion or scattering.

These are shown in figure 1 (a-d).

Consider the case of two intersecting streets, each having building walls on both sides. For direct radiation, the building corner provides a direct cutoff and the receiver can only receive sound radiated from the shaded zone shown in figure 2a. If there are no buildings, the receiver has an unlimited view as the vehicle travels the entire street (fig. 2b). Figures 3a and 3b show the paths by which a source can contribute to a receiver via a first reflection when buildings are present.

Figure 4 illustrates the four distinct first reflections for sources across the intersection from the receiver. Figure 5 illustrates one section of multiple reflections accounted for by the method of images.

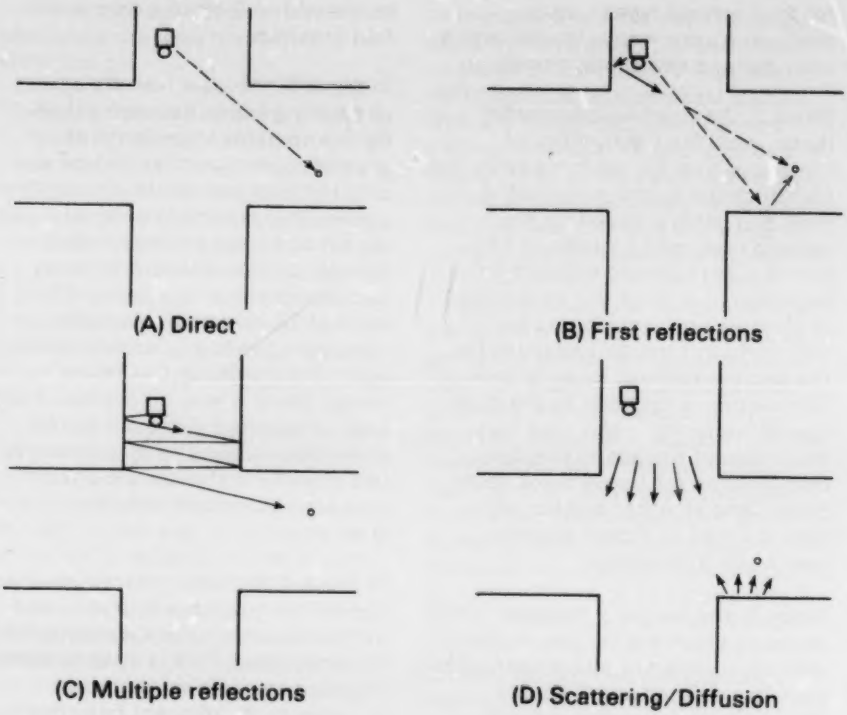


Figure 1.—Four mechanisms by which a vehicle approaching an intersection can radiate sound into a cross street.

Generally the diffusely radiated sound in the presence of a cross street is described as a power flux modified by the reflection coefficients of buildings of arbitrary height. The power flow in each street direction is described by two second-order differential equations, solvable in terms of a Green's function, and added to give the total flux in the street and the flux issuing into the intersection. The diffuse power entering the intersection is apportioned to enter the other streets based on relative cross sectional areas of those streets.

The analytical formulation of the propagation model has been organized so that the ray path contributions to pressures and wall intensities on the receiver streets make use of exact source and receiver geometrics for direct paths and singly reflected paths (including the effect of geometry on ray blockage). The contributions of higher order reflection paths are approximated by placing the source and receiver lateral positions on the centerline of the street. All formulations include the effect of the building wall configuration on each street (2 walls, 1 wall on right, 1 wall on left, no walls) and of the combination of wall types involved in each source-receiver street pair.

Formulations have been created to match each possible pair of source-receiver street types. The number of alternative choices is large. However, based on relationships between the coordinates of alternative geometric configurations, analyses for such configurations may be generated by a simple transformation of coordinate configurations (such as those which are mirror images of each other, or which exhibit reciprocity relationships).

The computerized urban traffic noise prediction model for stop-and-go traffic is composed of a vehicle noise emission level data base, a traffic flow model based on NETSIM, and an urban noise propagation model. The model predicts the sound level at 1-second intervals for arbitrary positions and elevations at up to 40 positions. L_{EQ} and L_{10} may be had for up to 10 positions on each of 4 streets.

Prediction and Analysis of Highway Construction Noise

A program to provide assistance to State highway agencies for the prediction and abatement of highway construction noise has resulted in the development and validation of a highway construction noise prediction model.[3] A computerized version of the mathematical model will predict construction site noise levels in detail. Simpler methods based on either a programable hand-held calculator or manual use of charts and graphs are also available. During the planning and design stages of a highway project, these prediction methodologies may be used to assess anticipated construction noise impacts. The computer version of the model also serves as a design tool for evaluating noise abatement strategies based on equipment noise control, selective placement of equipment to modify noise propagation paths, rescheduling of construction tasks, and adoption of alternative construction processes.

The construction noise model is used to predict 8-hour equivalent sound levels, $L_{EQ}(8h)$, at receiver locations near a highway construction site, from a variety of equipment and operations. The prediction model is designed for users with minimal background in acoustics and provides acoustic emission data for a large variety of construction equipment. However, the model also has options that permit the entry of user-supplied data bases and, therefore, is also useful to acoustic specialists. Although acoustics expertise is not required to operate this program, some knowledge of highway construction procedures and equipment is needed.

[3] "Highway Construction Noise—Environmental Assessment and Abatement," by W. Bowlby and L. Cohn. Final report submitted to Federal Highway Administration under Contract No. DTFH61-81-C-00082. Not yet published.

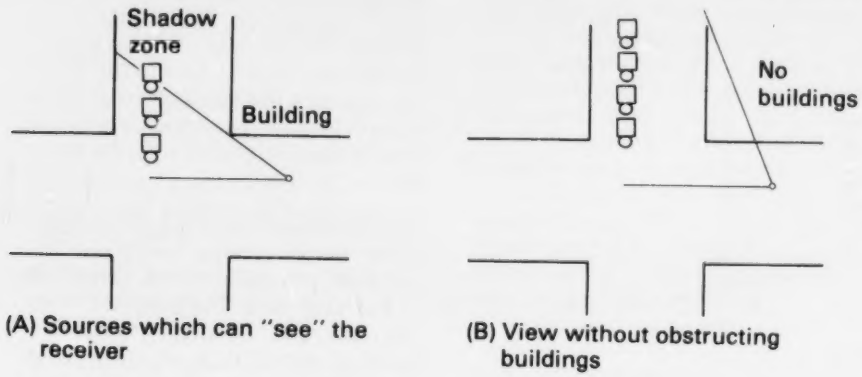


Figure 2.—Effect of a corner building in blocking direct sound radiated from a cross street.

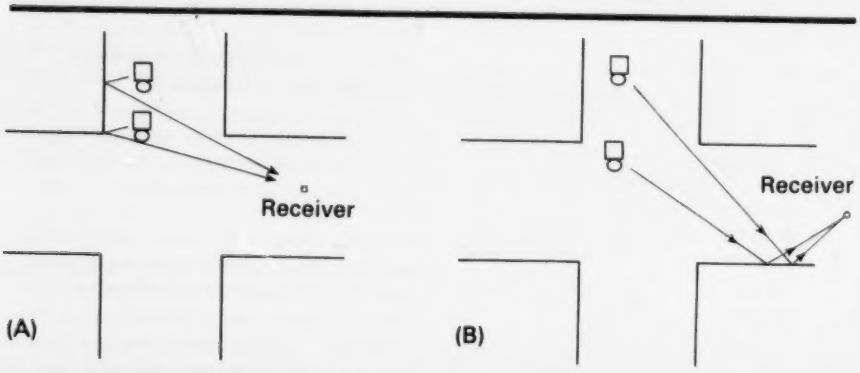


Figure 3.—Paths of a single reflection by which a vehicle radiates sound to a cross street receiver.

The computer model is an interactive program, where the user responds to data requests from the computer. It may be run from a video display or printing terminal. The program consists of two parts: HINPUT, which requests the input data from the user and performs initial acoustical and geometric calculations; and HICNOM, which performs the bulk of the acoustical calculations. HINPUT prepares a file containing the input data and initial calculations. This file is the input file to HICNOM, which prepares a report of the results.

Someone unfamiliar with computer programing or acoustics can use the program quite easily, but it also has a variety of options for the more experienced user regarding the types and operations of construction equipment.

Program capabilities

The computer version of the highway construction noise prediction model calculates an 8-hour equivalent sound level, $L_{EQ}(8h)$, at up to 10 receiver locations for construction activities representing various point, line, and area noise sources.

A useful and simplified approach was taken to predict L_{EQ} for engine-powered equipment because equipment noise levels are generally available as maximum levels, L_{MAX}. An "acoustic usage factor" was developed to relate L_{MAX} to the energy-average emission level required for calculation of L_{EQ}. This is statistically based on measured differences between L_{MAX} and L_{EQ} during the duty cycle of particular equipment.

Construction equipment has been classified into point, line, and area noise sources as follows:

- Point sources include compressors, jackhammers, and other stationary equipment.
- Line sources include scrapers, motor graders, and other equipment moving back and forth over the same path.
- Area sources include a bulldozer spreading dirt over a fill section of a project. Other examples are graders, compactors, and backhoes.

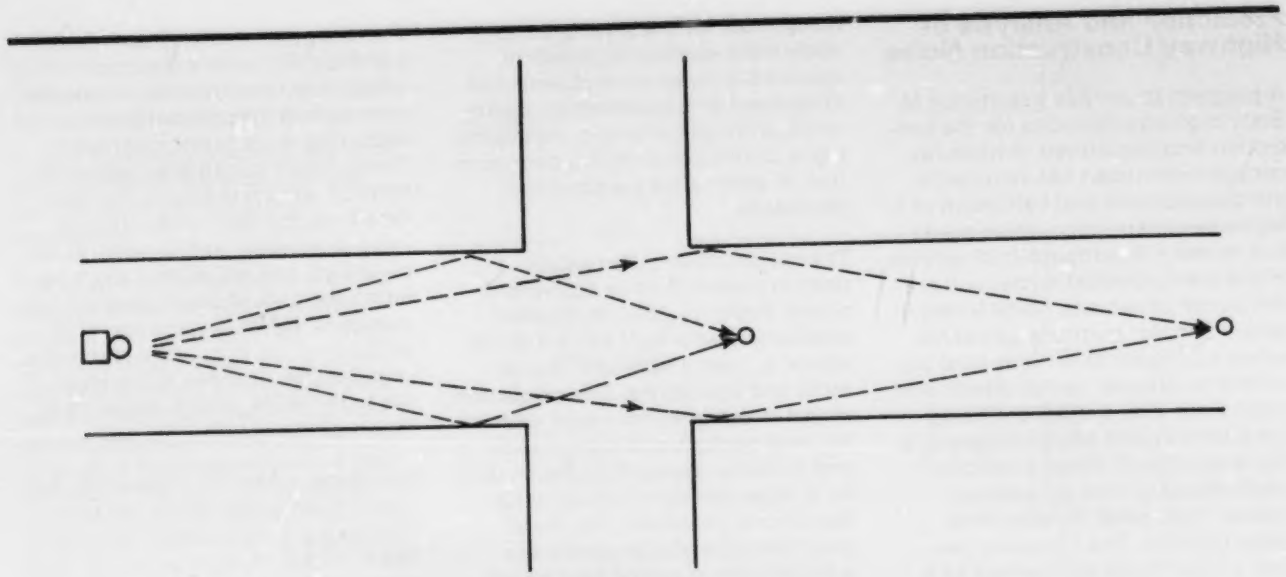
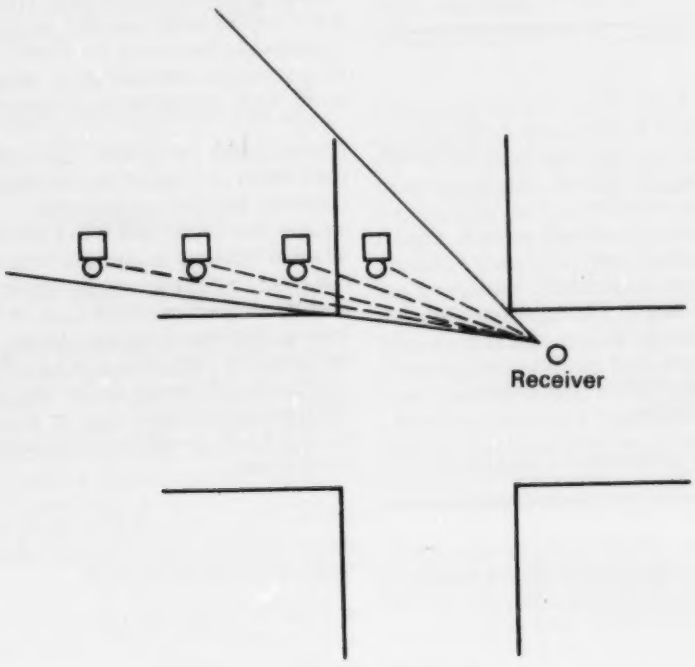


Figure 4.—Four paths of a single reflection by which a vehicle radiates sound to receivers across an intersection.

Figure 5.—Multiple reflections accounted for by the method of images.



Acoustically, the program analyzes point sources using an energy-averaged emission level and spherical wave propagation factored by an excess ground attenuation factor when appropriate. The model divides line sources into two subcategories: haul and nonhaul. Haul line sources (for example, trucks) are analyzed in a manner similar to the FHWA Highway Traffic Noise Prediction Model. (*2*)

Haul vehicles typically turn around either before or after loading or unloading to return to the other end of the haul road. The program includes routines to generate a series of straightline segments that approximate different types of turnaround loops. The model also computes average speeds on each segment based on the type of load, the approach and departure speeds, and the size of the loop.

The nonhaul line source analysis is analogous to point source analysis, with the point source contribution being integrated over the length of the line. Area sources are simulated as a series of parallel nonhaul line sources and analyzed accordingly. Finally, the program contains routines to predict noise barrier insertion loss for point sources and line source approximations.

The program is designed to handle a maximum of 10 point sources, 6 line sources, 5 area sources, and 3 noise barriers.

Also included is a built-in data base for over 50 types and models of construction equipment. However, this data base may be expanded to include nearly 300 emission levels. Users may also specify their own emission level data for construction equipment.

Certain types of equipment in the program have production rates, that is, they are constrained in their operation by their capacity (a dump truck) or by how long it takes them to perform one cycle of operation (a loader filling trucks). If two such pieces are working together on an actual construction site, their activities will be coordinated; for example, the number of trucks on a haul road in a specified period of time depends on the ability of the loader to fill them. The program is set up to compute this working relationship based on the production capability of each piece of equipment.

The following features are noteworthy:

- When 2 pieces of mobile equipment are operating together, the activity levels of one may be keyed to the duty cycle of the other so the noise contribution will be based on one duty cycle.
- Excess ground attenuation is specified by the user for each receiver location.
- Haul road turnaround loops and acceleration/deceleration profiles are automatically generated.
- A diagnostic output identifies the contribution of each source to the overall noise.
- For easy identification of output data, the user may supply descriptive names for each receiver, source, and barrier.

The highway construction noise prediction model has been validated at a limited number of construction sites. Generally the predictions are accurate to within 3 dBA. Further evaluation of the accuracy will be performed as the prediction tool is applied to construction sites.

Summary

This article has presented three noise prediction models. Together these procedures provide the methodology for performing all highway related noise assessments with greater accuracy and flexibility than has previously been available. These improvements are dependent on more detailed input data than previous prediction tools. Consequently the user of the computer based models faces a greater time commitment for the gathering and coding of site specific input data.

Acknowledgments

The following persons are recognized for their technical contributions leading to development of the noise prediction models discussed in this article: Professors J. M. Lawther, O. McDaniel, and S. I. Hayek of the Pennsylvania State University for the development of a highway traffic noise propagation-barrier attenuation prediction procedure; Professors S. Slutsky and W. McShane of the Polytechnic Institute of New York for the formulation of an urban noise prediction model for stop-and-go traffic; and Dr. K. Plotkin of Wyle Laboratories and W. Bowlby of Vanderbilt University for the development and refinement of a highway construction noise prediction model.

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(1) F. F. Rudder, Jr., et al., "Users Manual: FHWA Level 2 Highway Traffic Noise Prediction Model, STAMINA 1.0," Report No. FHWA-RD-78-138, *Federal Highway Administration,* Washington, D.C., 1978. PB 80 162340.

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[4]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Reliability of Locked-Wheel Skid Resistance Tester Confirmed

by
Rudolph R. Hegmon

Introduction

Highways play a major role in the economy of industrialized nations by facilitating high speed transportation of passengers and goods. To safeguard the initial investment, it is essential to provide for continuing maintenance and periodic upgrading. Periodic evaluation of pavement skid resistance is one of the requirements of pavement management. This article examines the problems in pavement friction measurement and the results of a Federal Highway Administration (FHWA) staff study[1] on the reliability of the locked-wheel skid resistance tester.

The ability to safely maneuver a vehicle in traffic, without skidding, depends on the interactions between the vehicle's tires and the pavement. The forces in braking and steering maneuvers are reacted by friction forces in the tire-pavement contact areas. As a first approximation the required coefficient of friction is equal to the deceleration in braking (a/g) or the acceleration in cornering (V^2/rg).[2,3]

Accelerations in normal driving rarely exceed 0.2 g's, but in emergency maneuvers, levels of 0.4 g or greater are frequently reached; as the g level rises, pavement skid resistance becomes more important for maneuvering a vehicle safely. It is no coincidence that accident rates have been shown to increase when pavement skid resistance drops below 40 SN.[4] (*1*)[5] However, there are many pavements with skid resistance as low as 20 SN that have below average accident rates. (*2*) This shows that pavements do not fit into safe or unsafe categories by the simple requirement for minimum skid numbers published in the National Cooperative Highway Research Program (NCHRP) Report 37 (*3*), and endorsed in Highway Safety Manual 12. (*4*) Other factors also come into play, such as amount of traffic, roadway geometry, and the need for emergency maneuvers.

However, although skid accident probability cannot be predicted solely from a skid number (*5*), skid resistance testing provides a measure of pavement friction, which is one of the indices of pavement performance. (*6*)

Tire-Pavement Friction Measurement Methods

Emergency braking

Several years ago, emergency braking was used to measure pavement friction. (*7*) In this method, the driver applies full brakes at a predetermined speed to lock the wheels. The distance it takes for the vehicle to

[1]The staff study "Friction in Cornering and Braking, Steady State and Transient" was conducted under the Federally Coordinated Program of Highway Research and Development (FCP) Project 1H, "Skid Accident Reduction."
[2]a = deceleration.
g = gravity acceleration.
[3]V = speed.
r = radius of curvature.

[4]The skid number, SN, is defined as 100 times the coefficient of friction as measured by the standard test method.
[5]Italic numbers in parentheses identify the references on page 101.

come to a full stop is measured and the coefficient of friction computed from the dissipated energy.

This test method, with a skidding distance of 30 m (100 ft) and more, is inherently unsafe. To make it safer, variations on this method were developed. For instance, directional stability can be maintained if one front wheel and the opposite rear wheel are locked while the others continue to rotate. (*8*) In another variation, the deceleration between predetermined initial and final speeds is measured, and the car does not need to come to a full stop. (*9*)

But even with these improvements, there are problems in friction testing with a braking vehicle. The tests cannot be performed on highways without impeding traffic. Also, because skid resistance on wet pavements is always lower than on dry ones, testing is done on wet pavements and this requires some means for uniformly wetting the surface. Experience has also shown that the dynamics of the automobile affect the test results. That is, different automobiles, or the same automobile with different loads, should not be expected to perform alike. For all these reasons skid resistance testing with a braking automobile has been discontinued, except for special studies.

Locked-wheel skid resistance tester

Friction test equipment was needed that would provide the information previously obtained in vehicle braking tests. The locked-wheel skid resistance tester became the generally accepted test method in the United States. It is used at regular driving speeds without interfering with traffic, it carries its own water supply and wetting system, and its operating cost is low, even though the initial cost is relatively high. The tester was designed to use a full-size automobile tire, with load, inflation pressure, and construction representative of tires in use. The only difference between the standard test tire and regular passenger car tires is in the tread design. The test tires have plain, circumferential ribs.

Friction measured with the test tire is of the same order of magnitude as would be measured by a regular production tire (fig. 1), and measured stopping distances are highly correlated with skid numbers (fig. 2). (*10, 11*)

Over the years, skid resistance testers have improved and most testers in use today meet the standard specifications developed by the American Society for Testing and Materials (ASTM). (*12*) Also, calibration methods have been developed that help maintain tester accuracy. (*13*) An NCHRP study demonstrated how tester precision can be improved, and accurate data obtained through calibration techniques. (*14*) This study also showed that most skid testing errors were a result of inadequate procedures in tester operation and data analysis. Skid resistance tester Calibration and Correlation Centers established by FHWA brought further improvements in tester performance. (*15*) In addition to calibrating the testers and subsystems, these centers provided informal operator training, a forum for exchange of experience, and assistance in tester maintenance.

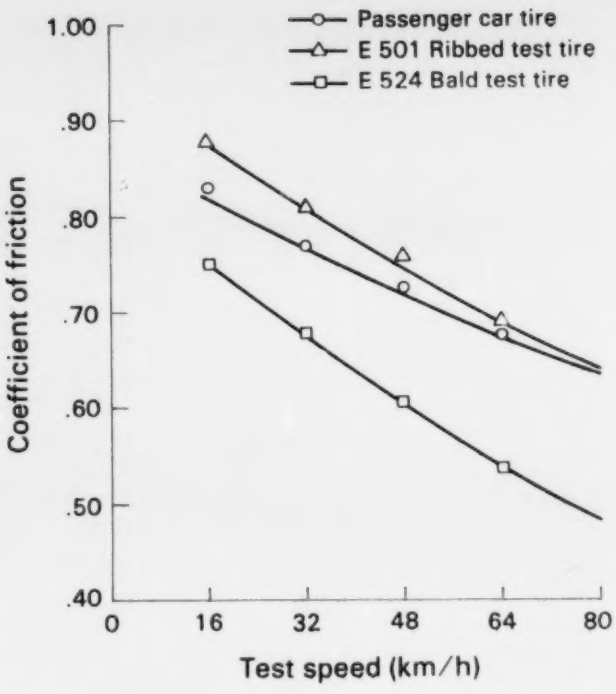


Figure 1.—Coefficient of friction versus speed for three tires. (10)

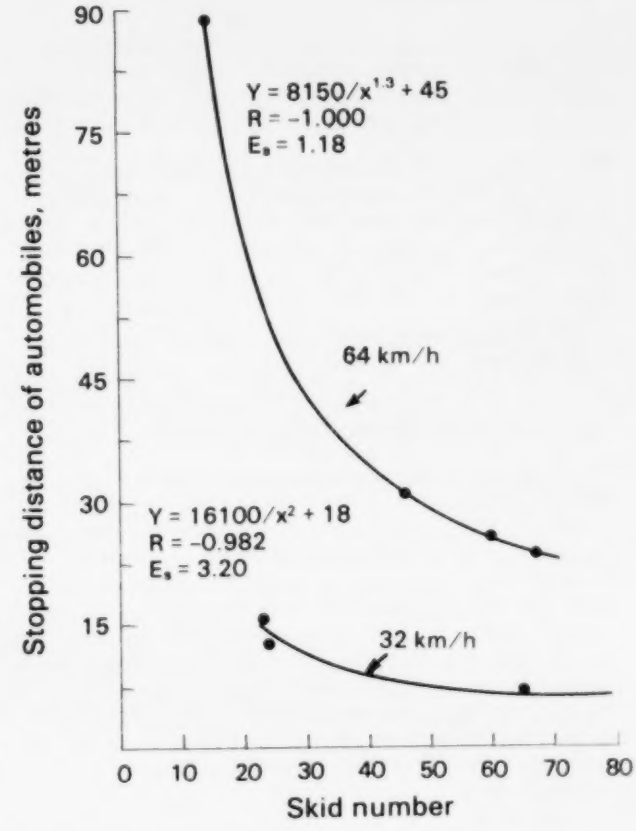


Figure 2.—Stopping distances of automobiles versus skid numbers for 32 and 64 km/h (20 and 40 mph) test speeds. (11)

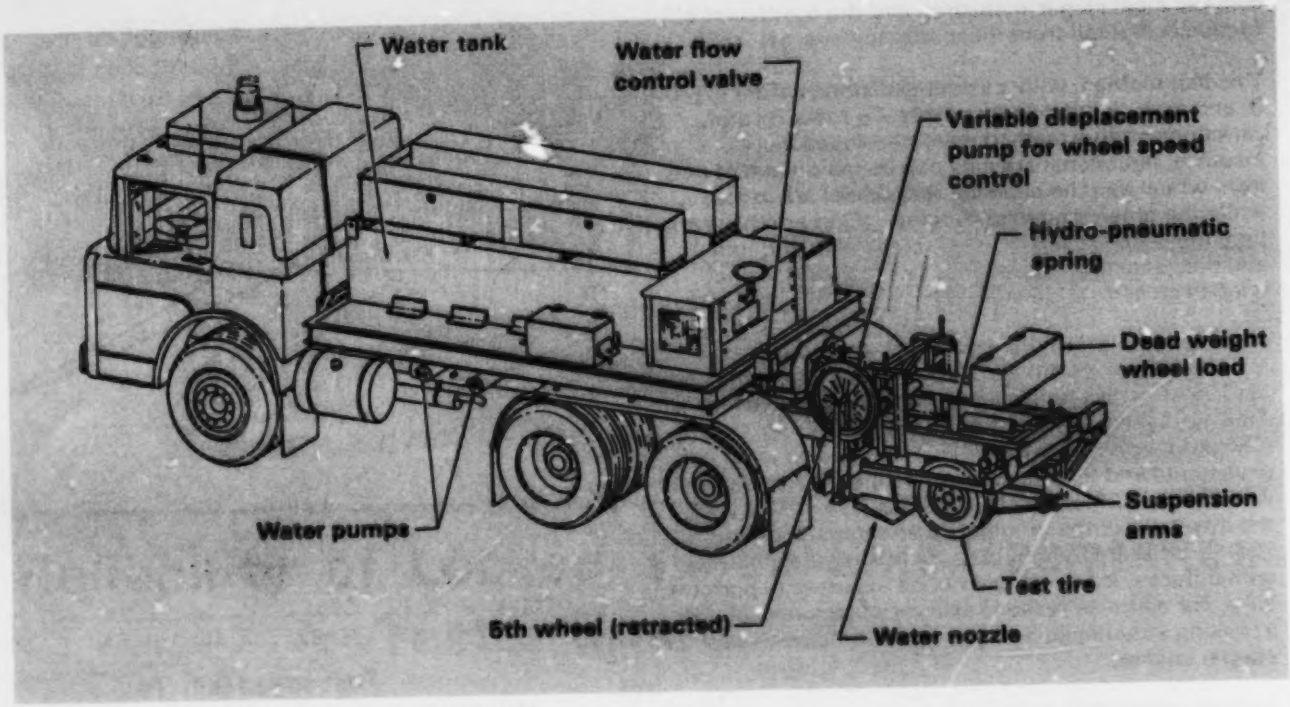


Figure 3.—Mobile Tire Traction Dynamometer (MTTD). (19)

Study Objectives

Although the improvements and increased accuracy of skid resistance testers have led to a high level of confidence in skid resistance measurement, some questions have been raised concerning the locked-wheel method:

- Is a measurement made with a locked wheel, sliding at constant speed, representative of the interaction between tires and pavements during all types of vehicle maneuvers? (*16*) Tires on vehicles undergo more complex interactions during braking, cornering, and avoidance maneuvers than straight-ahead skidding.
- What other methods of measurement, beside the locked-wheel method, are or could be used?
- Are such other methods equivalent, that is, do they rank pavement surfaces in the same order?

The objective of the staff study was to determine if different test modes rank pavements similarly, and if pavement friction measurements in any one test mode are valid for all the different vehicle maneuvers. To answer these questions, a few different test modes were considered to be absolutely necessary. In addition to the standard locked-wheel tests, these included testing at longitudinal slip values that give the peak friction force and testing with a yawed wheel to determine maximum side friction force. Similar tests would also have to be made under transient conditions, which resemble driving conditions better than steady state testing does.

Test Program

Testing equipment

Equipment for running the tests described above was not available in-house. An effort was begun to design the needed equipment, but was halted because similar equipment—the Mobile Tire Traction Dynamometer (MTTD)—was being built by the Safety Research Laboratory (SRL) of the National Highway Traffic Safety Administration (NHTSA).

The MTTD design is similar to the mobile tire tester constructed by the Cornell Aeronautical Laboratory for the Air Force (*17*), and a similar unit operated by the Highway Safety Research Institute of the University of Michigan (*18*), but includes some improvements. The MTTD has the capability to test in many of the modes under consideration. An overall view of the completed MTTD is shown in figure 3, and a complete description can be found in reference 19.

The MTTD was to be used for comparing and evaluating a number of different test modes, one being the standard locked-wheel test. The MTTD is a much more complex machine than a standard skid resistance tester; it has different dynamic response, and the test wheel is an integral part of the test vehicle. It was, therefore, of interest to determine how well locked-wheel tests with two such different testers would compare. Tests were run on four surfaces at the National Aeronautics and Space Administration's (NASA) Wallops Island (smooth and coarse concrete, smooth and coarse asphalt) at 32, 64, and 96 km/h (20, 40, and 60 mph). The overall

correlation between these 12 tests, each with 6 replicates, was 0.988. A typical result is shown in the graph of figure 4.

Having determined that MTTD locked-wheel tests are equivalent to standard trailer tests, it was agreed to use the MTTD in the planned research. An interagency agreement for a coordinated test program was signed with NHTSA.

Some additions to the MTTD were necessary for the FHWA test program. As designed the MTTD has a single test wheel that can be operated in the braking mode, the yaw mode, and a combination of these. To put the wheel in a yaw position a hydraulic cylinder turns it at some angle from the straight forward position, similar to the steering action in an automobile. The wheel is also connected to a hydraulic motor by a drive shaft. Changing the motor's speed causes the wheel to slip relative to its free rolling speed. The locked-wheel condition is provided by mechanically blocking the wheel. Thus the braking operation of the MTTD is quite different from the braking process in an automobile. When brakes are applied in an automobile the rate of slowdown depends not only on the brake application, but also on the tire-pavement interaction. This is not true when braking with the hydraulic motor. Therefore, a second braking mode was provided by adding an automotive disk brake as an alternate system. An electronic brake control system was also included, because such controls became available at the time as optional equipment on cars and trucks.

Test modes

In planning the test program it was clear that several different test modes were necessary. Indirect test methods were ruled out because of the limited understanding of tire-pavement interactions. (*20*) Test modes to be considered should duplicate, to some degree, the behavior of a vehicle's tires during various normal and emergency maneuvers. This requirement limited the choice to testers with automotive tires and measuring at regular travel speeds. The 15 different test modes that were identified are listed and briefly discussed below.[6]

Mode 1: Fast braking to wheel lock (about 0.5 sec) at 0° yaw angle. (This mode is used as a reference test to supply the standard ASTM skid number. The 100 percent condition is held for 1.5 seconds, the test speed is 64 km/h (40 mph), and wetting is at a rate of 0.6 L/min/mm (4.0 gal/min/in) of wetted width.)

Mode 2: Slow braking to wheel lock (about 5.0 sec) at 0° yaw angle.

Mode 3: Steady state braking slip at 0° yaw angle to identify peak braking coefficient. Slip incremented in steps of 5 percent, between 0 to 45 percent.

Mode 4: Fixed yaw angle and fast braking to wheel lock (about 0.5 sec) at 8° yaw angle.

Mode 5: Fixed yaw angle and slow braking to wheel lock (about 5.0 sec) at 8° yaw angle.

[6]Modes 1 through 6 must use the hydraulic motor to retard the test wheel. Modes 10 through 15 must use the disk brake. Modes 7, 8, and 9 may be done with either system, however, with the hydraulic motor system the drive shaft must be removed.

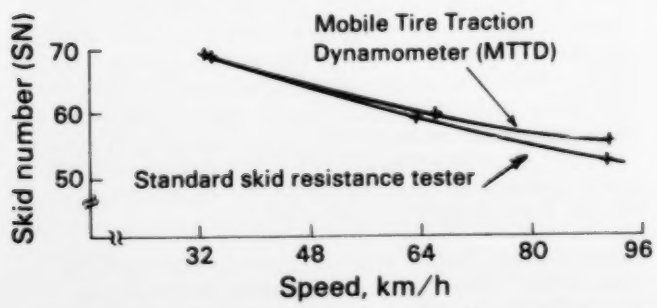


Figure 4.—Skid number versus speed.

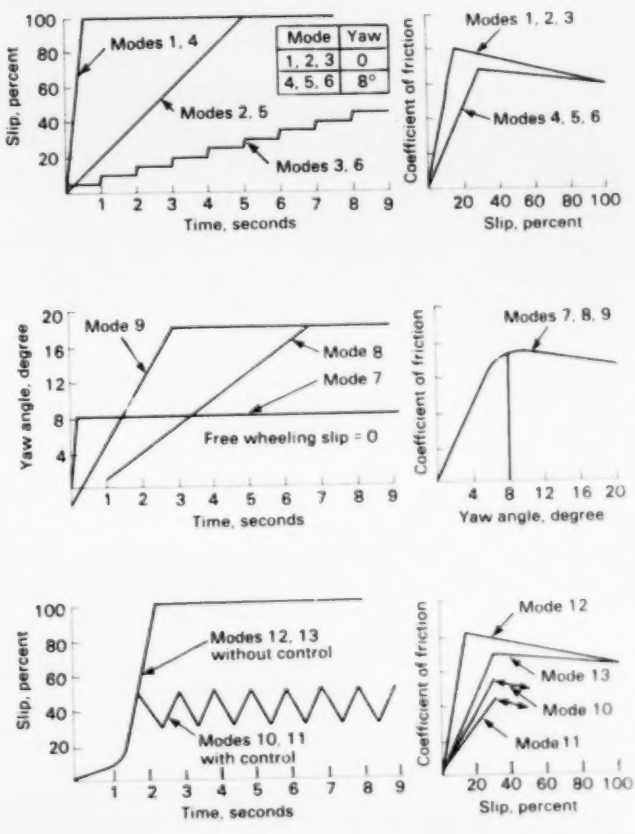


Figure 5.—Test mode schematics.

Mode 6: Steady state braking slip at 8° yaw angle to identify peak braking coefficient. Slip incremented in steps of 5 percent, between 0 and 45 percent.

Mode 7: Free rolling (0 percent braking slip) at constant yaw angle of 8°.

Mode 8: Free rolling and slow sweep of yaw angle (3° per sec) between −2° and +18°.

Mode 9: Free rolling and fast sweep of yaw angle (10° per sec) between −2° and +18°.

Mode 10: Transient slip with disk brake and brake control (0° yaw angle).

Mode 11: Transient slip with disk brake and brake control (8° yaw angle).

Mode 12: Transient slip to wheel lock with disk brake but without brake control (0° yaw angle). (This mode is the standard ASTM skid resistance test when all conditions [speed, wheel load, wetting] conform to ASTM Method E 274. [*12*])

Mode 13: Transient slip to wheel lock with disk brake but without brake control (8° yaw angle).

Mode 14: Transient slip with disk brake and brake control, slow sweep of yaw angle (3° per sec) between −2° and +18°.

Mode 15: Transient slip to wheel lock with disk brake but without brake control, slow sweep of yaw angle (3° per sec) between −2° and +18°.

Application of the test modes (except Modes 14 and 15) is shown in figure 5. In Modes 1 through 6 the hydraulic motor increases the slip at a selected rate (upper graphs). In Mode 7 the yaw angle is held constant, while in Modes 8 and 9 the yaw angle increases at a constant rate (center graphs). In Modes 10 and 11 the brake control system prevents the wheel from going into 100 percent slip; in Modes 12 and 13 the brake control is deactivated and wheel slip increases fast beyond about 15 percent slip (bottom graphs). Schematics of the corresponding friction curves are also shown. An actual recording of the wheel speed and friction force variations during brake control application is shown in figure 6.

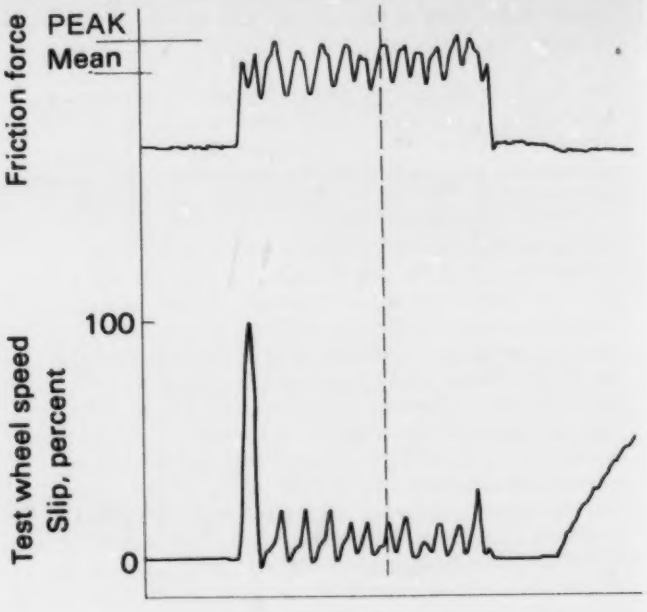


Figure 6.—Record of wheel slip and corresponding friction force with brake control system operating.

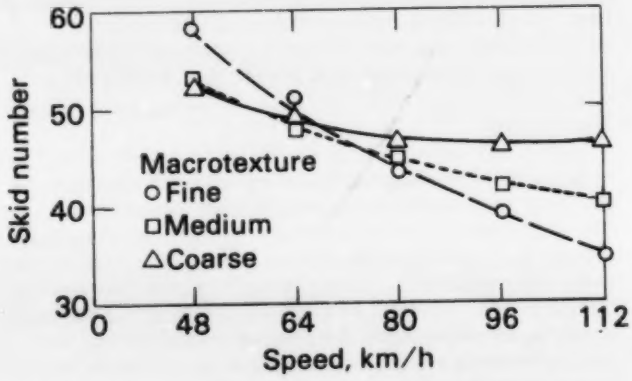


Figure 7.—Speed gradients for three groups of pavements. (23)

Other considerations

Measured at the standard test conditions, skid resistance on wet pavements generally ranges from 20 to 60 SN, depending on the pavement surfaces. Seasonal and short term variations of skid resistance may cause changes by as much as 30 SN. (*1*) Effects of exposure to changing weather conditions are strongest on limestone aggregates. (*21*) Such short term changes can affect the outcome of correlation programs.

Many different production tires as well as the standard ASTM test tire (*22*) were included in this cooperative test program with the Safety Research Laboratory. (This article treats only ASTM tire data.) Combined test sequences were agreed upon to reduce the need for frequent mode changes, some of which are quite time consuming. Temperatures and weather conditions changed during the several days it took to complete such test sequences. To compensate for the short term changes of the test surfaces, frequent control tests were run and used to correct the test data. However, these corrections did not produce the expected results and were discontinued. To avoid similar problems during the remainder of the test program, testing with the ASTM tire was separated from the other tire tests so a complete sequence could be finished in 1 day. It was learned from this experience that correlation programs on pavement friction measurements should be conducted in the shortest possible time.

Another major factor in skid resistance testing is the test speed. Generally, skid resistance decreases as speed increases. The rate of decrease is a function of

macrotexture, and thus varies from pavement to pavement (fig. 7). (*23*) To develop a valid correlation between different test modes (or different testers), the test program must be run on a number of different pavements and at several different speeds.

Test Pavements and Sequences

Because a good range of different pavement surfaces was not available in one location, the testing was done in four different areas.

The first tests were run on two surfaces at the Army's Aberdeen Proving Grounds in Maryland: A bituminous concrete runway, and a 1.6 km (1 mile) loop of bituminous concrete with a Jennite coating, which reduced the skid resistance to about 20 SN.

The runway was barely used by aircraft and therefore had a uniform surface with a high skid resistance of 65 SN. The shakedown tests for the MTTD were run on this surface. After correcting some minor malfunctions, the first test sequence, Modes 1 through 9, was conducted. The disk brake system, needed for the other modes, had not yet been installed.

A second test sequence on the same surfaces was run about 2 years later. The skid resistance on the runway had dropped from 65 to 52 SN. Based on the interim results, only four modes (9, 10, 12, and 13) were tested.

Three test sequences were run over 6 months at the Ohio Transportation Research Center (TRC), a newly opened facility that has a large, bituminous concrete area designed for vehicle dynamics testing, and a long, portland cement concrete pad for skid resistance testing. The concrete pad consists of six parallel lanes with texture increasing from smooth to coarse, and coarse textured, bituminous concrete shoulders.

Because of the almost new condition, skid resistance was high on all surfaces. Three surfaces were selected: One lane on the skid path (TRC-1), one of the shoulders (TRC-2), and the vehicle dynamics test area (TRC-3). The skid resistance ranged from 52 to 65 SN. The three test sequences included regular production tires so it was impossible to run all modes at one time. Modes 7, 8, 9, 10, and 12 were run in April; Modes 3 and 6 in August; and Modes 1, 2, 4, and 5 in October. The skid resistance of the vehicle dynamics test surface dropped from 65 to 62 to 57 over the 6 months. During the long breaks between test sequences, partial data analyses were made.

Additional tests in Modes 9, 10, 12, and 13 were run on the four surfaces at NASA's Wallops Island (smooth and coarse portland cement concrete, and smooth and coarse bituminous concrete) and on two surfaces used by the Pennsylvania Transportation Institute (a new, unopened stretch of Interstate with a grooved portland cement surface, and a fine textured, sand-filled epoxy surface).

Test Results

Preliminary findings

Although initially 15 test modes were identified, some of these were expected to be impractical, while others might be redundant (no significant differences found between the results of some of the modes). One of the first tasks in the test program was to reduce the number of modes to a more manageable size by weeding out the impractical and redundant modes. After a few trial runs Modes 14 and 15 were dropped. Both of these modes simulate braking in a turn, a condition which often leads to spinout. To achieve acceptable repeatability in these tests, the brakes need to be applied after a given level of sideforce has been reached. This was impossible to control. The tests were run with a fixed time lag between steering input and brake application, but the sideforce developed during this time interval varied too much and the two modes could not produce repeatable data.

Mode 11 was also dropped. Both Modes 10 and 11 used the automatic brake control, which prevents wheel lock-up. The brake pressure is cycled about a slip value at which the coefficient of friction is highest. In practice the mean friction value at 0° yaw angle was lower with brake control than without (76 versus 94). This result was not unexpected. Like any feedback control system, brake control activation lags the feedback signal. Brake pressure and wheel slip cycle about the optimum (fig. 5) and the mean friction values are therefore lower. The value of antiskid systems is not in reducing stopping distances, but in preventing loss of control because of skidding wheels. The corresponding peak value for braking at 8° yaw angle without brake control was 73. Also the standard deviations in Mode 10 were much higher than in any other mode (table 1). This high standard deviation means that for a given number of replicate tests the confidence interval is larger, or for a desired precision a larger number of replicate tests must be run. For example, a skid resistance measurement with a standard deviation of 2 SN at five replicates as recommended in the standard test method (*12*) will result in a confidence interval of 2.5 SN. (*14*) If the standard deviation is about 6 SN (as in Mode 10), the corresponding confidence interval would be 7.5 SN. Conversely, to achieve the same precision of 2.5 SN about 20 replicate tests would have to be run instead of 5. Thus, it became clear early in the program that testing with brake control was not a good choice because of poor repeatability. Mode 10, however, was retained to accumulate more data for a better evaluation of the merits of this test mode.

A complete series of tests was run on the three surfaces at the Ohio Transportation Research Center. No significant differences were found when the results of the various modes were compared. Table 2 lists the range of mean values for Modes 1, 2, 3, and 12 (braking at 0° yaw angle) and Modes 4, 5, and 6 (braking at 8° yaw angle). The differences in test results between the different modes were random within each group.

Therefore, the narrow ranges of the mean friction coefficients prove that no significant differences exist within each of these groups of test modes.

Similarly the test results in the three cornering modes (7, 8, and 9) were very close (fig. 8). The peak coefficients are about the same, but before the peak is reached there is a significant difference between the fast and slow yaw rates. Any differences before the peak friction do not measure the friction potential of the pavement. Such differences are caused primarily by tire characteristics. Only the peak values are of interest for measuring the maximum side friction coefficient of pavements. Thus, for pavement friction testing the three cornering modes are equivalent.

Because of these findings, further testing was limited to four modes—9, 10, 12, and 13. All of these could be run with the automotive brake system, so use of the hydraulic motor for the braking tests was discontinued. This simplified the test program and saved a great deal of time and effort. The remainder of the test program could be completed in a relatively short time, eliminating the need to account for pavement changes during testing. Table 3 shows the final test series and the equivalent, discontinued modes.

Before discussing the final test series, some observations from the preliminary tests should be made (tables 1 and 2). The peak friction values are much lower at 8° yaw angle than in straight-ahead braking. This, of course, is not unexpected. The same effect occurs when braking in a turn, that is, the available braking force is reduced. This reduction can be explained by a pavement-tire friction model called the friction ellipse (fig. 9). It shows that the total available friction is limited. As the demand for longitudinal (in the wheel plane) friction increases, the available cornering friction decreases. Figure 10 is a record of the braking and sideforce friction as wheel slip is increased. On the other hand, with the locked wheel, the coefficient of friction at 8° is not much lower than at 0° yaw angle. Typical test data are shown in table 4. In this example the friction coefficient reaches a peak of 0.643 at 40 percent slip and decreases to 0.526 for the locked-wheel condition. The sideforce coefficient, with a constant yaw angle of nominally 8°, decreases from a high of 0.732 to 0.228 at 40 percent slip and to 0.053 for the locked-wheel condition. Thus, at the peak friction coefficient the sideforce coefficient is about one-third the peak value; with the locked wheel, it is about one-tenth the locked-wheel coefficient.

In addition, table 2 shows that the effect of speed is much greater in locked-wheel sliding. The gradient, defined as the change of the coefficient of friction divided by the corresponding change in speed, is about twice as large in the locked-wheel mode as in the peak friction mode.

These results show that there are no significant differences in the ranking of pavement friction when tested in any of the modes in this test program. This conclusion must be qualified; the same test tire must be used in all modes. Selection of a particular test mode should therefore be based on other criteria.

Table 1.—Mean standard deviations in twelve test modes

Mode	For coefficient of friction at peak[1]			For coefficient of friction with locked wheel[2]		
	30 mph	40 mph	50 mph	30 mph	40 mph	50 mph
Braking at 0° yaw angle						
1	—	4.6	3.8	—	2.7	2.7
2	—	4.2	3.7	—	2.1	2.9
3	—	2.2	3.6	—	—	—
10	5.2	6.3	6.4	—	—	—
12	3.3	3.5	3.5	1.9	2.5	2.5
Means (without Mode 10)	3.3	3.6	3.6	1.9	2.4	2.7
Braking at 8° yaw angle						
4	—	2.5	4.8	—	2.3	2.8
5	—	3.4	3.3	—	3.2	1.6
6	—	1.8	2.8	—	—	—
13	2.6	2.2	2.4	1.8	2.6	2.4
Means	2.6	2.5	3.3	1.8	2.7	2.3
Cornering[3]						
7	—	2.2	2.9	—	—	—
8	—	4.2	3.2	—	—	—
9	2.9	4.4	3.2	—	—	—
Means	2.9	3.6	3.1			

1 mph = 1.6 km/h
[1]Mean standard deviation for all peak braking modes = 3.1.
[2]Mean standard deviation for all locked-wheel modes = 2.3.
[3]Mean standard deviation for all cornering modes = 3.2.

Table 2.—Range of mean friction coefficients on three pavements

Mode	At peak			With locked wheel		
	40 mph	50 mph	Gradient	40 mph	50 mph	Gradient
Braking at 0° yaw angle: 1, 2, 3, 12	92—99	89—96	.30	54—59	46—54	.65
Braking at 8° yaw angle: 4, 5, 6	68—74	65—70	.35	53—54	43—50	.70
Cornering: 7, 8, 9	82—95	77—91	0.4			

1 mph = 1.6 km/h

Correlation Between the Principal Test Modes

In the final phase of the test program a balanced set of data was collected on eight test sites and at three speeds. The data included peak friction values in cornering (Mode 9), peak friction values with the brake control system (Mode 10), and both peak and locked-wheel friction values in straight-ahead braking (Mode 12) and braking with an 8° yaw angle (Mode 13). These six friction values were analyzed in simple, one-to-one correlations. Table 5 lists the correlation coefficients.

The locked-wheel friction measurements in Modes 12 and 13 are highly correlated (0.96). The correlation between the peak friction coefficients is only slightly lower (0.93), although the 8° yaw angle reduces the peak friction coefficient by about 25 percent (table 2). All other correlations are lower, but still satisfactory. Correlation coefficients of better than 0.8 were computed for the peak friction coefficients of Mode 10 (with brake control) with each of the peak friction coefficients in Modes 12 and 13. Correlations between peak friction coefficients and locked-wheel coefficients ranged from 0.56 to 0.78. These are still significant correlations. Finally, the sideforce coefficient is highly correlated with both locked-wheel coefficients (0.86 and 0.88) and with the peak friction coefficient at 8° yaw in Mode 13 (0.86). The correlations with the peak friction coefficient in straight-ahead braking are lower (0.61 in Mode 10, 0.76 in Mode 12).

Table 3.—Disposition of test modes

Mode in final test program	Equivalent modes
9	7, 8
10	—
12	1, 2, 3
13	4, 5, 6

Table 4.—Relation between longitudinal and sideforce coefficients in Test Mode 4 (fast braking at fixed yaw angle)

Percent slip	Yaw angle degree	Friction coefficient	Sideforce coefficient
0.0	8.1	0.000	0.732
5.0	7.6	0.303	0.657
10.0	7.8	0.470	0.557
30.0	8.1	0.630	0.298
35.0	8.0	0.638	0.253
40.0	8.1	0.643	0.228
45.0	8.2	0.640	0.207
50.0	8.2	0.635	0.176
95.0	7.9	0.530	0.064
100.0	8.0	0.526	0.053

Summary and Conclusions

Interpretation of research findings

Analysis of the test results has not produced any evidence that different modes of friction testing will result in a different ranking of pavement surfaces. The less-than-perfect correlations between test modes do not reflect differences in ranking, but are caused by random errors in the measurements. It is very difficult to achieve good repeatability in friction testing, even under well-controlled laboratory conditions. Friction testing on highways is much more difficult to control and the best one can hope for is to hold the measurements within a 10 percent error. NCHRP Report 151 has identified the various error sources in locked-wheel friction testing. (*14*) It can be assumed that the same error sources are present in all pavement friction test modes to a greater or lesser degree. These errors combine and partially cancel each other, resulting in an overall error that cannot be further reduced.

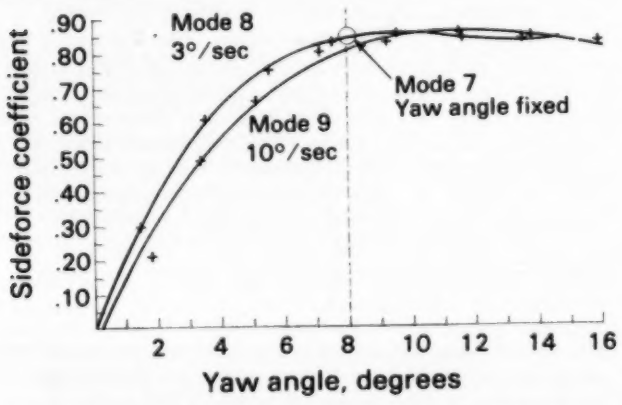
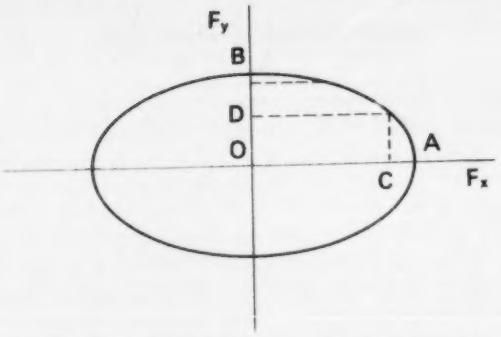


Figure 8.—Sideforce coefficient versus yaw angle for E 501 test tire, fast and slow yaw rates.

The standard deviation is a commonly used measure of random errors or the lack of repeatability in a series of tests under presumably identical conditions. Table 1 shows that locked-wheel tests had an overall standard deviation of 2.3, versus over 3.0 for the peak friction and side friction modes. This is not surprising because the test condition in the locked-wheel mode is uniquely defined. The other two modes attempt to determine the maximum friction in braking and cornering. These maximums do not always develop at the same values of wheel slip or slip angle. Thus, testers operating at a fixed wheel slip or slip angle do not always measure maximum friction. A sweep through the wheel slip or slip angle should, in theory, be able to find the maximum. In practice, however, identifying the maximum in the instant it occurs is so difficult that the additional complexity of a sweep mechanism is not justified. Undoubtedly, these uncertainties in measuring the peak values are the primary reasons for the larger standard deviations.

One of the reasons for undertaking this study was the question "Is a measurement made with a locked wheel,



$\overline{OA}$ Peak friction force F_x at 0° yaw angle
$\overline{OB}$ Peak side friction force F_y at zero slip
For combined slip and yaw angle
peak friction force reduced to $\overline{OC}$
peak side friction force reduced to $\overline{OD}$

Figure 9.—Concept of interaction between longitudinal friction F_x and side friction F_y for tire-pavement traction forces.

sliding at constant speed, representative of the interactions between tires and pavements during all types of vehicle maneuvers?" The mechanism of these interactions is obviously different. However, based on the test results it can be concluded that the friction rating of pavements by the locked-wheel method is valid for all maneuvers. In other words, a pavement found to be slippery by a locked-wheel friction test will be slippery for all maneuvers. This study did not, and was not designed to, define at what level of skid resistance a pavement becomes hazardous. This level depends on many factors, but does not depend on the mode of measurement.

Even though the ranking does not depend on the mode of testing, the friction scales do. Table 2 shows peak and sideforce coefficients about 70 percent greater than the locked-wheel coefficients. This means that pavements with a marginal skid number of about 30 SN would be measured at about 50 on the peak friction and side friction scales. Such pavements, by the simple relationship between the coefficient of friction and acceleration, should be safe, because accelerations of 0.5 g are hardly ever experienced by drivers. The problem is that these peak values are available only over a very small range of the slip (or slip angle) range. Beyond these values the available friction decreases. Drivers cannot maintain the brake or steering inputs to take advantage of the maximum available friction. In theory, this is what brake control systems should do. But because of the need to cycle the brake (fig. 5), the effective coefficient of friction is about the same as in locked-wheel sliding.

Discussion and recommendations

As long as there is a need for pavement friction testing, the locked-wheel test method should continue to be used. Such testers have been used for more than 10 years and replacements may be needed in the near future. There seems to be no reason to switch to another test method, but consideration could be given

Table 5.—Pairwise correlation coefficients

	SFC 9[1]	PFC 10[2]	PFC 12	LWC 12[3]	PFC 13	LWC 13
SFC 9	1.0	0.61	0.76	0.86	0.86	0.88
PFC 10		1.00	0.86	0.56	0.82	0.61
PFC 12			1.00	0.64	0.93	0.70
LWC 12				1.00	0.73	0.96
PFC 13					1.00	0.78
LWC 13						1.00

[1]SFC is the sideforce coefficient in Mode 9.
[2]PFC is the peak friction coefficient in the indicated mode.
[3]LWC is the corresponding locked-wheel coefficient.

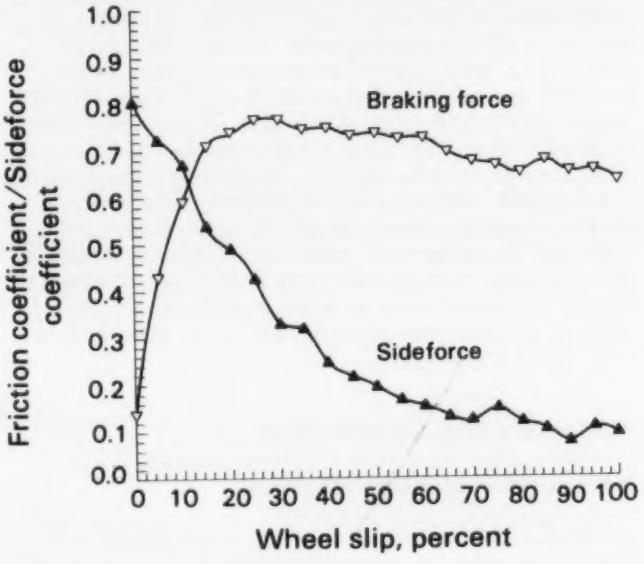


Figure 10.—Decrease of sideforce coefficient, as wheel slip increases.

to further improving and possibly simplifying the skid resistance tester. The basic mode of operation, however, should be retained.

Two operational arguments have often been made against using a locked-wheel mode. One addresses the excessive, and often nonuniform, wear on the tire. It is true that this is a disadvantage of locked-wheel testing, but wear could be reduced by reducing the normal load on the tire. Currently the load is specified as the tire design load. It is known, however, that the coefficient of friction does not change much with load changes. Therefore, it may be timely to consider a 10- or 15-percent reduction in wheel load. Such a reduction would also reduce the power requirement for the tow vehicle.

The second point of argument is the inability to conduct continuous tests with a locked wheel because of the high wear rate. The wheel is normally locked for about 30 m (100 ft), a sufficiently long sample for any purpose. Even if it were needed, continuous testing would deplete the water supply very quickly. Thus, in practical

terms, the need to sample short pavement sections is not really a disadvantage.

There is no evidence that a systematic evaluation of friction testing modes had been made when the first locked-wheel skid testers were constructed. The almost universal adoption of this test mode in the United States may have been fortuitous, but it also turns out to have been a fortunate decision.

Acknowledgments

The author would like to acknowledge the following persons for their contributions to the test program described in this article: Messrs. Arthur Neill, Pat Boyd, and John Hinch of NHTSA's Safety Research Laboratories, who conducted the test program and preliminary data analysis; and Miss Linda G. Faigen, a co-op student, who did most of the statistical analysis.

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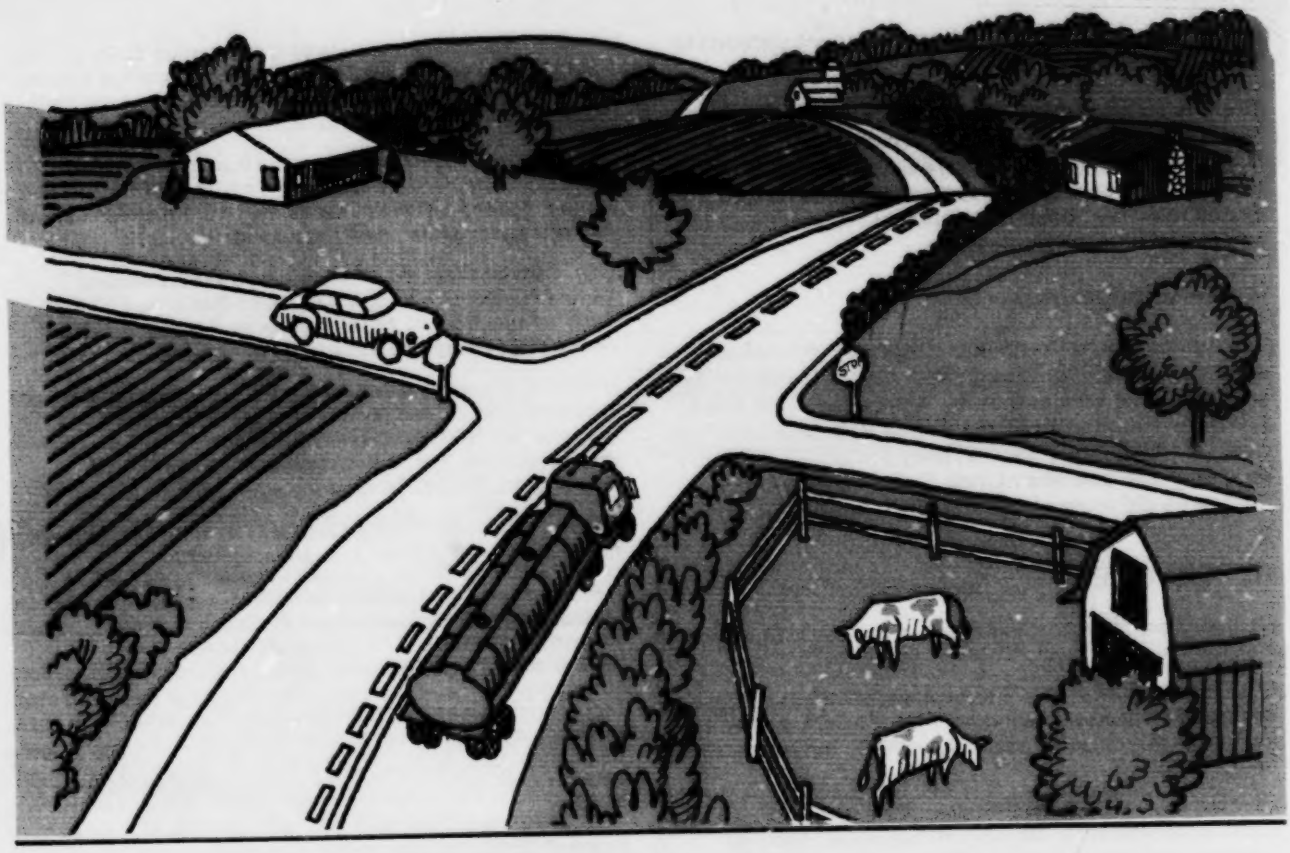
[7]Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.



Intersection Control and Accident Experience in Rural Michigan

by
Harry S. Lum and Martin R. Parker, Jr.

Introduction

The basic purpose for Stop sign control of an intersection is to provide orderly and safe movement of traffic through the intersection. Stop signs provide orderly movement by assigning the right-of-way and safe movement by warning motorists of a hazardous situation. In most cases, low-volume intersections are Stop controlled[1] rather than uncontrolled or Yield controlled. It is estimated that 95 percent of nonsignalized low-volume intersections in Texas are Stop controlled. (*1*)[2] Data extracted from an ongoing Federal Highway Administration (FHWA) contract "Geometric Treatments for Reducing Passing Accidents at Rural Intersections on Two-Lane Highways" showed that 96 percent of 885 randomly sampled nonsignalized intersections were Stop controlled. It is hard to believe that such a high percentage of low-volume intersections are unduly hazardous or that most motorists approaching such intersections do not know who has the right-of-way. Regardless of the type of control, the driver on the minor road must not enter the intersection when a vehicle on the major road is close enough such that entry by the driver on the minor road would "constitute an immediate hazard." (*2*)

A study has been conducted in selected counties of Texas, New York, and Florida to investigate the

[1]This article does not consider multiway Stop-controlled intersections, only intersections having Stop control on one of the intersecting roadways.

[2]Italic numbers in parentheses identify references on page 105.

use and need for Stop control at low-volume intersections. (*3*) The findings of the study were as follows: (1) Stop signs do not reduce accident experience at low-volume intersections, and (2) Stop signs are being used even where there is adequate sight distance. However, the sample size in this study was rather small—only 140 intersections.

This article reports on a similar, but more extensive, study conducted in rural Michigan. In the Michigan study almost 900 intersections were examined based on type of control and related accident experience.

Principal Variables

The principal variables considered in the Michigan study were sight distance, volume, and speed. Both sight distance and volume at Stop-controlled and uncontrolled intersections were directly examined. Approach speed, while not specifically examined for its effect on accident frequency, was accounted for in the development of the sight distance criteria. Moreover, because the study was limited to two-lane rural roads, the approach speed on the major road did not vary much from one intersection to another.

Sight distance

All traffic engineers agree that sight distance is a critical criterion for the use of Stop control. They disagree, however, as to what the distance should be. The following sight distance criteria were used in the Michigan study analysis:

a. Restricted—less than the stopping sight distance.[3]

b. Marginal—stopping sight distance plus an additional distance up to 61 m (200 ft).

c. Unrestricted—stopping sight distance plus an additional 61 m (200 ft) or more.

These criteria are based on the formula presented in the Transportation and Traffic Engineering Handbook. (*4*) Table 1 presents the distribution of examined intersections by control mode and sight distance criteria. The basic hypothesis (null) was to determine if Stop-controlled and uncontrolled intersections are independently distributed over the different sight distance criteria. In testing this hypothesis, the minimum discrimination information statistic (m.d.i.s.) analogous to the chi-square test statistic was used. (*5*) The test indicated that Stop-controlled and uncontrolled intersections are proportionally distributed over the three sight distance criteria. Thus, the data do not support the supposition that Stop signs are used at intersections where sight distance is poor; Stop signs are being used even where sight distance is unrestricted.

Table 1.—Distribution of rural intersections in Michigan by control mode and sight distance criteria

Control mode	Sight distance criteria			
	Restricted	Marginal	Unrestricted	Total
Stop controlled	401	112	339	852
Uncontrolled	10	7	16	33
Total	411	119	355	885

Volume

The Michigan data were also examined relative to volume. For this data base, all minor roadways had traffic volumes less than 500 vehicles per day (vpd).

The major volumes for all uncontrolled intersections were less than 1,000 vpd. The volume analysis in table 2 is for Stop-controlled and uncontrolled intersections with major and minor volumes not to exceed 1,000 and 500 vpd, respectively. The results show, using m.d.i.s., that there is no significant difference in accident frequencies for Stop-controlled and uncontrolled intersections for the two minor volume categories. In table 2, the data for three-leg and four-leg intersections are grouped together. Table 3 separates the data for three-leg and four-leg uncontrolled intersections to determine if any significant difference in accident frequency was observed. Because of the small cell sizes for the four-leg intersections, an extension of the Fisher-Yates exact statistical method (*6*) was used to evaluate the probability of obtaining the displayed distribution. The probability of obtaining the observed number of intersections with the given accident frequencies was 0.52, which is

[3]Stopping sight distance is the sum of two distances: (1) the distance a vehicle travels after the driver sights an object and before braking, and (2) the distance the vehicle travels after braking. (*4*)

Table 2.—Distribution of intersections with accidents (1978-1980) by control mode and minor roadway volumes (major roadway volume is limited to 1,000 vpd)

Control mode	Minor volume			
	0-225	226-500	Total	Percent
Uncontrolled:				
Number with accidents	10	7	17	63
Number without accidents	6	4	10	37
Total	16	11	27	100
Stop controlled:				
Number with accidents	80	30	110	67
Number without accidents	33	20	53	33
Total	113	50	163	100

Table 3.—Distribution of uncontrolled intersections by frequency of accidents and number of approaches

Number of approaches	Frequency of accidents			
	0	1	2+	Total
Three-leg	10	12	7	29
Four-leg	1	3	0	4
Total	11	15	7	33

far from being significant at the 5 percent level. Thus, the observed data showed no significant relationship between accidents and number of approaches for uncontrolled intersections.

Accident Experience

The assertion is sometimes made that Stop signs are effective as traffic control devices because fewer accidents occur when they are used. To test this assertion, it would be desirable to conduct a controlled experiment and observe the frequency of accidents for both Stop-controlled and uncontrolled intersections under similar traffic and road characteristics. The experiment would have two phases:

1. Observe the accident frequency at uncontrolled intersections for a specified length of time. Change the intersections to Stop controlled and observe the accident frequency for an equal time period.

2. Reverse the procedure—observe Stop-controlled intersections first, then change to uncontrolled.

Although it is ideal, this approach would be very difficult to implement. First, greater use of Stop signs is not encouraged, and second, it is extremely difficult, legally and politically, to remove Stop signs once they are installed. Also, because of the low frequency of accidents at rural intersections, a large number of intersections would have to be observed for such an experiment to be statistically valid.

Although the Michigan study did not use the ideal approach described above, the resulting data can provide some insight into the relative safety of Stop-controlled and uncontrolled intersections and the assertion that fewer accidents occur when Stop signs are used can be assessed. Examination of table 4 shows that there is no statistical difference at the 5-percent significance level in the distribution of accident frequency between the three-leg and four-leg approaches for Stop-controlled intersections, nor is there any difference between the Stop-controlled and uncontrolled intersections. Because available data were limited for uncontrolled intersections with volumes greater than 1,000 vpd, extension of the analysis of table 4 was not possible.

It should not be concluded from table 4 that uncontrolled intersections are as safe as Stop-controlled intersections and Stop signs can be removed. Table 4 only shows that Stop signs alone do not guarantee fewer intersection accidents. The decision to use Stop signs should be based upon sound engineering practice, such as that presented in the Manual on Uniform Traffic Control Devices. (*7*) It states, as one condition, that Stop signs may be warranted where there is a combination of high speed, restricted view, and serious accident record.

Table 4.—Distribution of intersections by frequency of accidents and control mode (major volume limited to 1,000 vpd, minor road volume limited to 500 vpd), 1978-1980 inclusive

Control mode	Frequency of accidents 0	1	2	3	Total
Stop:					
Three-leg	32	46	9	4	91
Four-leg	21	28	14	3	66
Uncontrolled	10	12	4	1	27
Total	63	86	27	8	184

Summary and Discussion

In the Michigan study sample of almost 900 low-volume nonsignalized intersections, 96 percent were Stop controlled. Other findings from the Michigan study are as follows:

a. Stop signs are being used where there is adequate sight distance.

b. There is no relationship between the number of approaches on the minor roadway and accident experience for major volume under 1,000 vpd.

c. Accident experience at Stop-controlled intersections is neither better nor worse than at uncontrolled intersections under 1,000 vpd.

The findings of the Michigan study substantiated those of the study conducted in Texas, New York, and Florida. (*3*) The results of both studies suggest that the extensive use of Stop control at rural intersections may not be necessary. For many situations where some form of control is needed, Yield control may be a better alternative.

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[4]Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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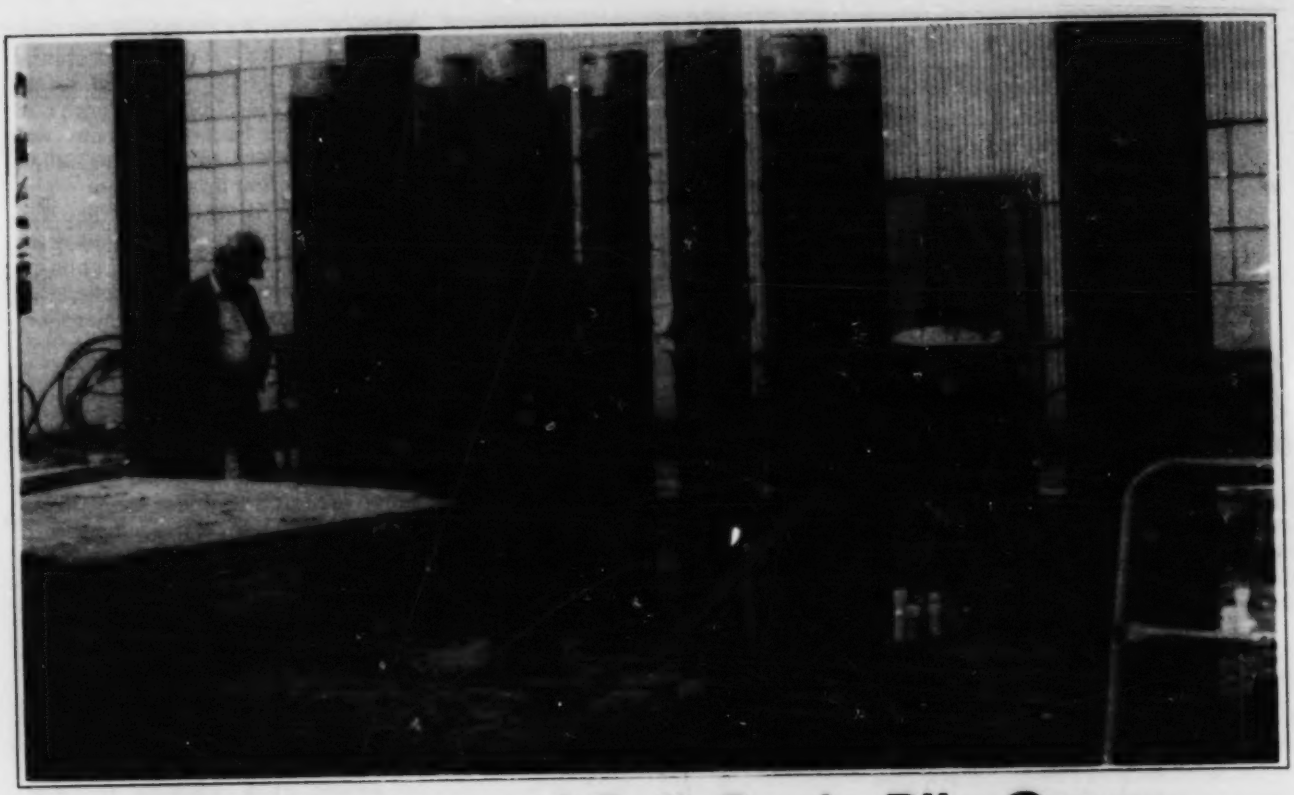


Observations of Full-Scale Pile Group Performance

by
Michael W. O'Neill and Andrew G. Heydinger

Introduction

A great deal of information is available on experiments involving full-scale pile group behavior. The bibliography on page 111 lists documents that describe the results of some 75 full-scale load tests and observations of vertically loaded pile groups in prototype structures in clay and sand. These tests and observations were analyzed to see if behavioral trends could be identified.

Before generalized behavior patterns can be derived from reported full-scale test data, the parameters that control such behavior must be identified. The parameters of most interest are efficiency and settlement ratio. Efficiency is defined as capacity of pile group/N times capacity of an isolated control pile, where N = number of piles in the group. Settlement ratio has several definitions, which have subtle differences. The definition used here is the ratio of settlement of the pile group to the settlement of an isolated control pile when the load on the group divided by the number of piles in the group is one-half the failure load of the control pile.

Evaluation of Failure

The capacity of an isolated control pile and pile group capacity, or "failure load," must be evaluated to assess efficiency and settlement ratio. Scores of methods exist for such evaluation. Figure 1 shows the four methods used by the authors in their analysis of the literature listed in the bibliography. With these methods, certain loads on the gross load-settlement curve (or envelope to a cyclic load-settlement curve) are evaluated as failure loads. If the control pile or pile group actually plunges into the ground under applied loading (fig. 1, lower diagram), all of the methods yield the same value and failure is clearly and consistently defined. When failure does not occur by plunging (as is the case with most single piles in granular soils and for many groups), the various methods yield different results.

In the terminal linearity method, point of failure is defined as the point on the load-settlement curve where the curve assumes a final linear shape. (*1*)[1] A different point of failure can be calculated by using a modification of the rational "offset" method proposed by Davisson (*2, 3*):

[1]Italic numbers in parentheses identify references on page 111.

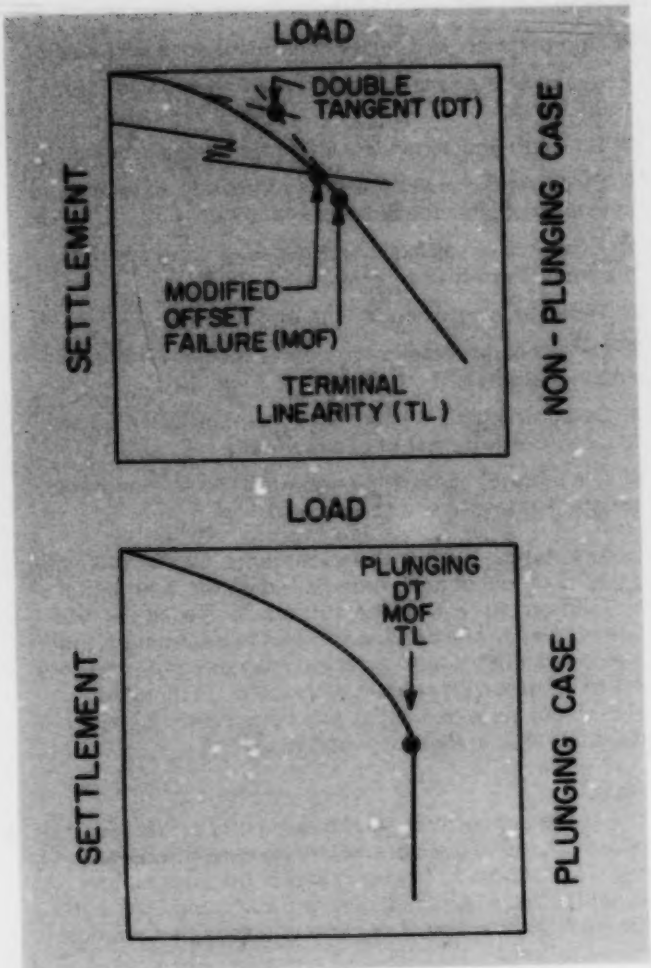


Figure 1.—Assessment of failure in piles or pile groups from gross load-settlement curve.

The factor 0.6 was added to the original equation to apply uniquely to friction piles and friction pile groups. Whenever the piles are predominately end bearing (a fact usually derived from a review of boring logs), that factor should be increased to 1.0.

Also shown in figure 1 is the double tangent method, in which the failure load is defined as the load at the point where extensions of the initial and final linear portions of the curves intersect.

Another rational method of defining failure is shown in figure 2. (*4*) In this method, failure load is defined as the load that causes an increase in creep settlement. The method requires a nonstandard test in which load is applied in equal increments and in equal time intervals.

A problem unique to interpreting failure loads in pile groups arises when the load is not applied at the exact center of reaction from the piles and the soil is strain softening to the extent that individual piles within the group can plunge. Whenever these two factors exist, the pile cap will rotate under load and failure will progress from pile to pile. As a result, the group failure load appears to be less than the sum of the failure loads of the individual piles, because the load-settlement curve for the center of the pile cap plunges before every pile in the group plunges. Figure 3 shows that this effect was clearly observed in a group of prismatic steel piles tested in stiff fissured clay (*5*) but was much less pronounced in a group of tapered timber piles in medium to dense sand. (*6*) The principal consequence of this effect is that group efficiency becomes a function of the degree of concentricity of load in strain-softening soils, both in test and prototype foundations. Because of this, group failure in uninstrumented test groups in strain-softening soils may be better inter-

$$S_{fc} = \frac{0.6L}{AE} Q_{fc} + 4 + \frac{B}{120} \text{ (mm)}$$

$$S_{fg} = \frac{0.6L}{AE} \frac{Q_{fg}}{N} + 4 + \frac{NB}{120} \text{ (mm)}$$

Where,

S_{fc} = Settlement at failure for control (single) pile
S_{fg} = Settlement at failure for pile group
Q_{fc} = Failure load for control pile (point on load-settlement curve corresponding to S_{fc})
L = Pile length
AE = Axial stiffness of a pile
B = Tip diameter of single pile
N = Number of piles in group

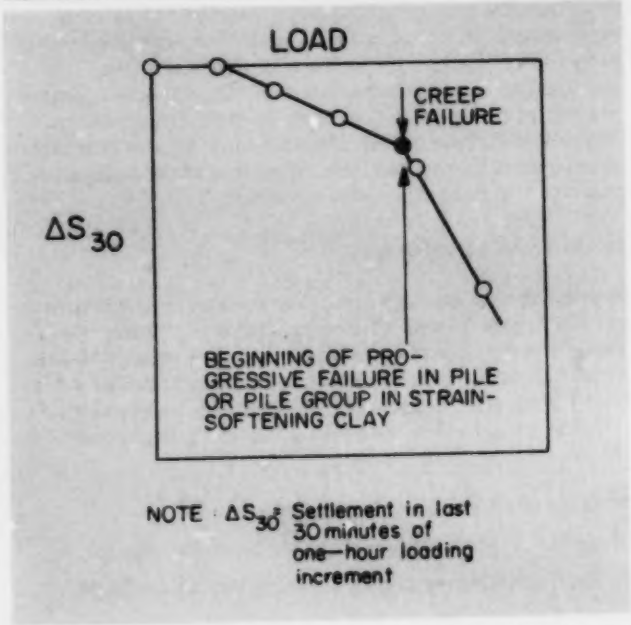
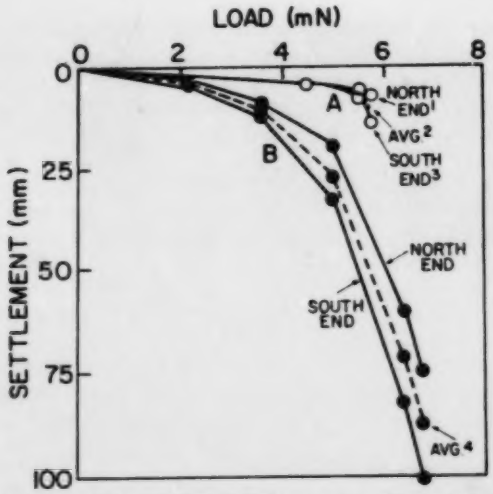

LOAD
CREEP FAILURE
ΔS30
BEGINNING OF PROGRESSIVE FAILURE IN PILE OR PILE GROUP IN STRAIN-SOFTENING CLAY
NOTE: ΔS30 = Settlement in last 30 minutes of one-hour loading increment

Figure 2.—Assessment of failure in piles or pile groups based on onset of high creep rate.



A. HOUSTON SITE · VERY STIFF CLAY, PRISMATIC STEEL PILES, STRAIN SOFTENING SOILS
(O'Neill, Hawkins, and Mahar, 1980) (5)

B. ALTON SITE · MED TO DENSE SAND, TAPERED TIMBER PILES, STRAIN HARDENING SOILS
(Woodward-Clyde Consultants, 1979) (6)

1. Did not plunge. 2. Plunged.
3. Avg. curve has shape characteristic of plunging.
4. Avg. curve has shape characteristic of extreme end curves.

Figure 3.—Problems associated with load-settlement curves in pile groups which rotate under load.

preted by defining failure as the onset of high creep rate (fig. 2).

Using one of the methods shown in figure 1, the authors have computed failure loads for each set of control pile and pile group tests reported in documents listed in the bibliography. Where plunging was reported, the plunging load was used as the failure load; where plunging did not occur, but where a terminally linear portion of the load-settlement curve existed, the terminal linearity method was used; where neither of the above conditions existed, the modified offset method was used. Occasionally, where complete data were not provided, the interpreted failure load given in the document was accepted.

Study Parameters

Presumably, if enough factors are taken into account, a consistent picture of efficiency, settlement ratio, and other effects could be obtained from the mass of test data. In addition to the failure loads, a number of variables must be included in correlating the test results. For short term behavior of driven piles and pile groups these include the following:

- Geometric details of the piles.
- Order and rate of pile installation in the group.
- Type of hammer and cushioning materials used.
- Type of installation aids used (jetting, preaugering, etc.).
- Hydraulic diffusivity characteristics of the soil.
- Compression and density characteristics of the soil.
- In situ stresses and piezometric conditions of the soil.
- Strength and sensitivity characteristics of the soil.
- Stress-strain characteristics of the soil, extending to several group widths below the pile tips.
- Existence of cap-soil contact and, if contact exists, the integrity of that contact.
- Time lapse between driving and testing.
- Details of the reaction system (especially if reaction anchors are used).
- Geometric details of the load (point of load application relative to center of pile reaction).
- The manner of loading employed (cyclic, monotonic, constant-rate-of-penetration, etc.).

Unfortunately, most of the documents cited in the bibliography do not contain sufficient data for meaningful correlations. However, the authors have tried to correlate efficiency and settlement ratio to parameters that are consistently cited—soil type (clay or sand), cap condition for group (in contact with soil or suspended above soil), pile spacing (s), pile penetration (p), pile diameter (d_m), and group width (B_{av}).

Results

The results of correlating efficiency and settlement ratio with the above parameters (in dimensionless form) are shown in figures 4 and 5. Because so few variables were included, only general trend lines can be drawn from the data. The general trends that emerge are as follows:

- Efficiencies are enhanced in clays when caps are in contact with the soil (although very large settlements are required to develop full group capacity in such cases) but are less affected by caps in sands.
- In sands, a slight trend toward higher efficiency appears when p/s increases if the cap is suspended, but the opposite effect seems to exist if the cap is in contact.
- Settlement ratios for groups of piles in both clay and sand tend to increase when p/s is increased, but no dependence of settlement ratio on cap contact can be observed.

Further studies of full-scale pile group behavior are badly needed. However, if such studies are to be useful additions to the body of knowledge on this subject, the governing parameters enumerated earlier must be carefully evaluated and reported. In particular, the effects of cyclic and long term loading, which are not considered in this article, may be studied economically by instrumentation and careful observation of inservice pile groups. It is expected that the results of such research will indicate that existing methods for evaluating group efficiency, settlement characteristics, and distribution of loads to piles are too conservative.

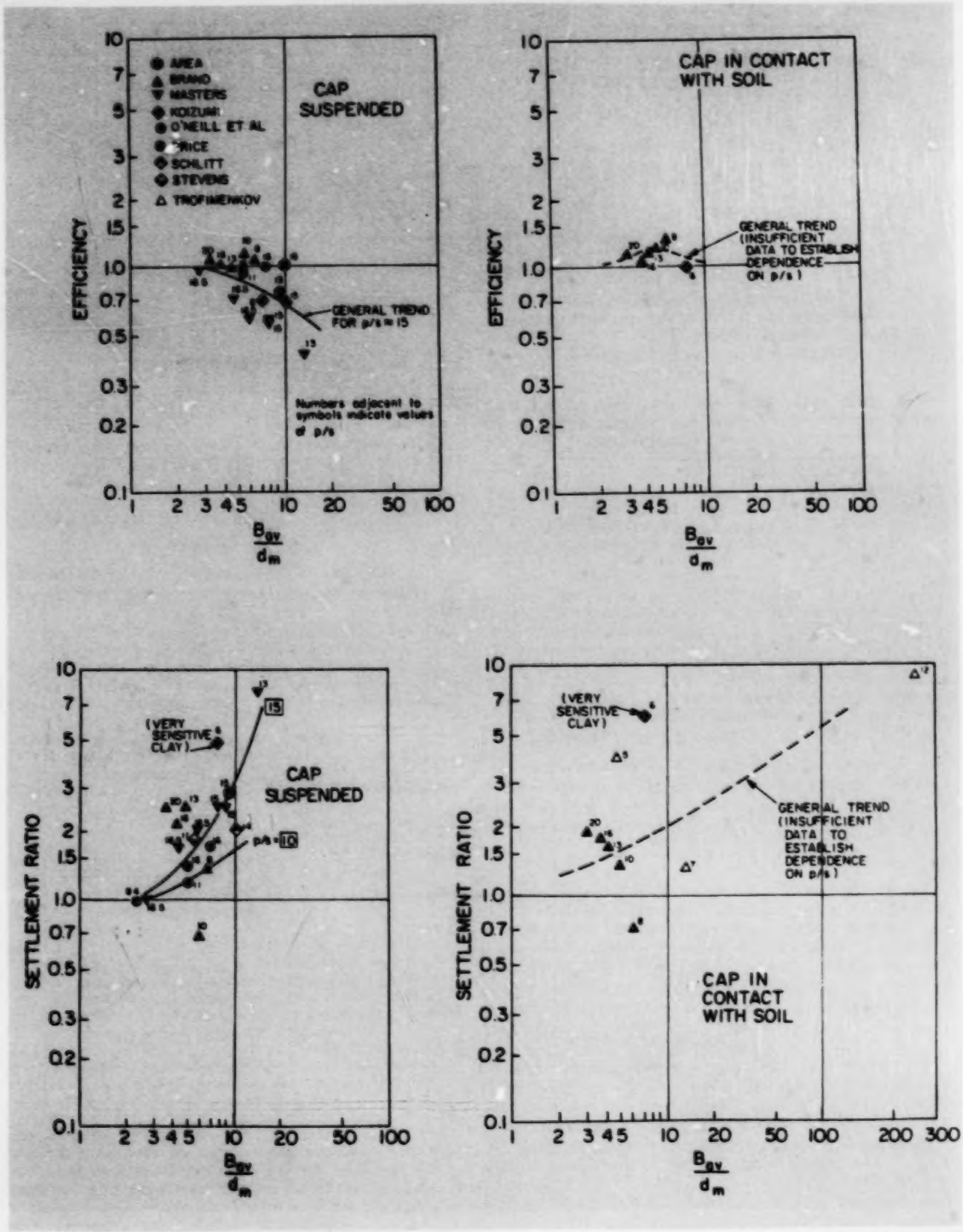


Figure 4.—Behavior of full-scale pile groups in clay.

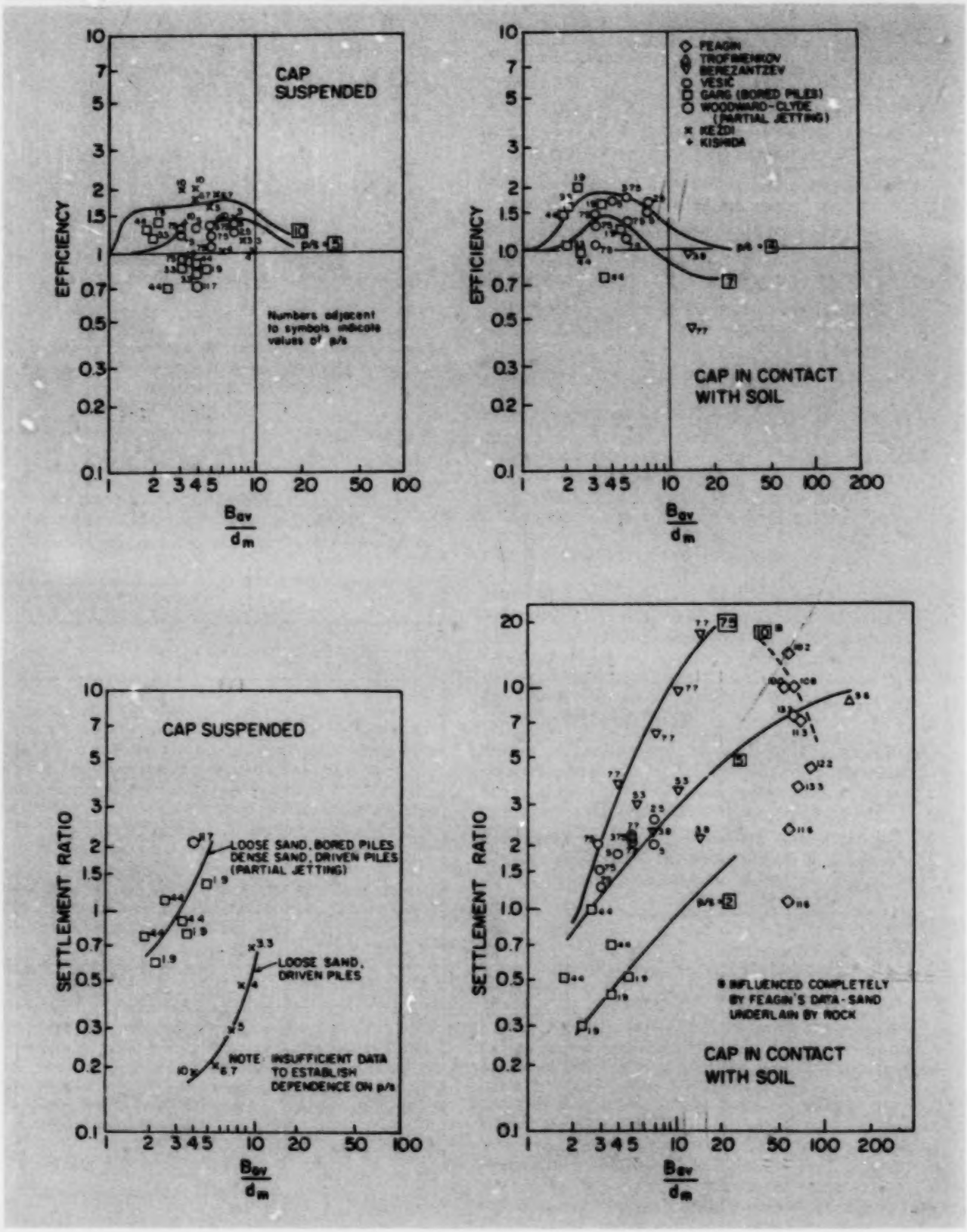


Figure 5.—Behavior of full-scale pile groups in sand.

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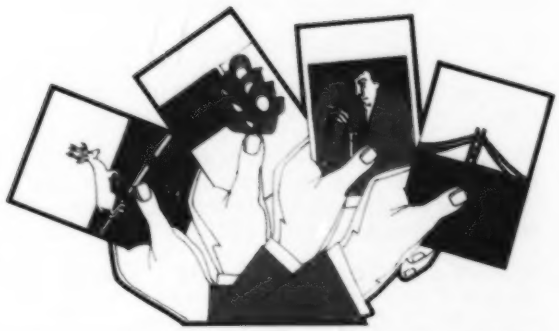
Michael W. O'Neill has served as a research associate for the Texas Center for Highway Research and manager of geotechnical engineering for Southwestern Laboratories, Inc. Since 1974, he has been on the faculty of the Department of Civil Engineering of the University of Houston, where he is now an associate professor.

Andrew G. Heydinger is a graduate student and instructor at the University of Houston and is involved with research on driven piles in clay. His experience includes geotechnical engineering and graduate study in Pittsburgh, Pa., and geotechnical engineering with the St. Louis District of the Corps of Engineers.

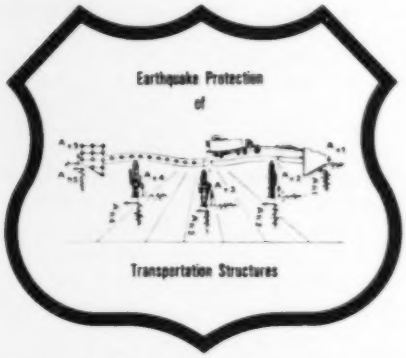
[2]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.



Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Office of Engineering and Highway Operations Research and Development (R&D) and Office of Safety and Traffic Operations R&D. The reports are available from the address noted at the end of each description.

Guidelines for Strong-Motion Instrumentation of Highway Bridges, Report No. FHWA/RD-82/016



by FHWA Office of Engineering and Highway Operations R&D, Structures Division

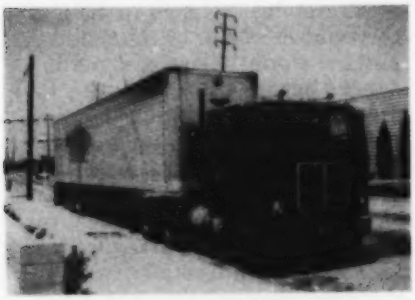
Catastrophic failure of some modern highway bridges during strong earthquakes has demonstrated how little is known about the dynamic behavior of bridges under seismic loading. As a result, State and Federal Government agencies have initiated programs to instrument selected bridges and obtain information that will lead to improving bridge performance in strong-motion earthquakes—those of sufficient magnitude to damage structures in the vicinity.

Strong-motion instrumentation permanently installed on bridges to sense and record ground or structural motion caused by a relatively large earthquake registers seismic motions as light traces on films, lines on a strip chart record, or analog or digital signals on magnetic tape. In all cases the motion is recorded as a function of time. The recorded motion is that of a fixed point on the bridge moving along a single axis. The motion is translated to an electrical or mechanical signal that is proportional to displacement, velocity, or (most often) acceleration, within some acceptable error.

This report presents guidelines for installing strong-motion instrumentation on highway bridges; includes discussions of strong-motion instrumentation characteristics and records, the objectives of instrumentation programs and criteria for selecting a bridge for strong-motion instrumentation, theoretical aspects of the linear dynamic behavior of bridges, technical aspects of the failure of highway bridges during the 1971 San Fernando, Calif., earthquake, recommended procedures for instrument placement on and adjacent to bridge structures, instrumentation types, installation techniques, and maintenance requirements; and presents a complete description of an inservice strong-motion instrumentation scheme installed on a continuous two-span bridge near El Centro, Calif. At present, eight highway overpass bridges and three long span bridges have been instrumented in the United States in accordance with the principles presented. These initial installations will provide dynamic response data, insight into improved future bridge strong-motion instrumentation plans, and significant information on instrument performance and reliability.

This report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 177452).

Significant Factors in Truck Ride Quality, Vol. I—Summary Report, Vol. II—Comprehensive Report, Vol. III—Data Compendium, Report Nos. FHWA/RD-81/138-140



by FHWA Office of Engineering and Highway Operations R&D, Structures Division

These reports document the results of a study to identify factors that significantly contribute to the differences in ride quality among various models and configurations of commercial long-haul trucks over a range of highway operating conditions. Full-scale field studies were conducted to measure dynamic motions and environmental variables in truck cabs and to record the drivers' subjective evaluations of ride comfort and the drivers' body motions as observed by a researcher riding in the passenger seat. Measurements were made in a baseline test vehicle operated under controlled test conditions and in 10 commercial long-haul trucks operated in typical over-the-road service on five categories of highway pavement. The baseline truck was a 3-S2, cab-over-engine tractor with a loaded, closed van, semitrailer. The route selected for the commercial vehicle inservice studies included 31 different pavement surface sections that were categorized as follows: smooth asphalt, smooth nearly new concrete, good concrete with some cracks and patches, faulted concrete with periodically displaced joints, and patched asphalt.

The data acquisition system included sensors for measuring cab air temperature and sound level and six accelerometers in the cab for determining vertical and front-to-back seat and floor motions. Each data channel was scanned 100 times per second; 10-second data samples were recorded intermittently at preselected road locations. Each record included a run identification, instrument calibrations, vehicle speed indication, and voice-logged location and subjective ratings. Vehicle characteristics compared included weight distribution, seat type, chassis suspension, and geometrical dimensions.

Data were gathered over a range of speeds to find the "worst" ride quality conditions. In the baseline vehicle cab a predominant 3.6 Hz motion frequency was observed to peak at 64 km/h (40 mph). The collected data were used to present various ride quality statistical spectra. The subjective ride quality ratings correlated fairly well with accelerations measured on the floor and seat in the truck cab. The dominant factors found to influence ride quality were pavement condition, wheel asymmetry, truck configuration and loading variation, and, to a lesser degree, cruising speed. No one type of vehicle provided a clearly superior ride.

These reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 82 126954, PB 82 126962, and PB 82 126970).

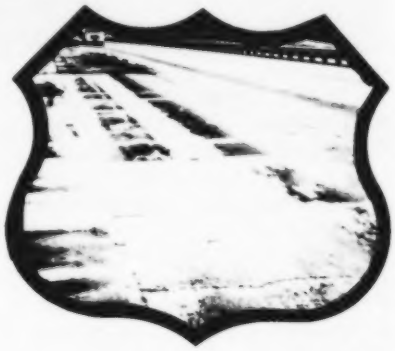
Improving Subdrainage and Shoulders of Existing Pavements, Report No. FHWA/RD-81/078

by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

This report describes methods for the design of subsurface drainage of pavements built on expansive soils and in areas of deep frost action. It also includes the results of channeling and pumping studies, a discussion of the effectiveness of curb and gutter drainage systems, and descriptions of equipment and procedures for maintaining and cleaning subsurface drainpipes. A general design philosophy is presented that emphasizes the importance of predicting and controlling moisture content when designing pavement subsurface drainage systems.

Limited copies of the report are available from the Pavement Division, HNR-20, Federal Highway Administration, Washington, D.C. 20590. The report also is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 225426).

A Pavement Moisture Accelerated Distress Identification System, Vols. 1 and 2, Report Nos. FHWA/RD-81/079-080

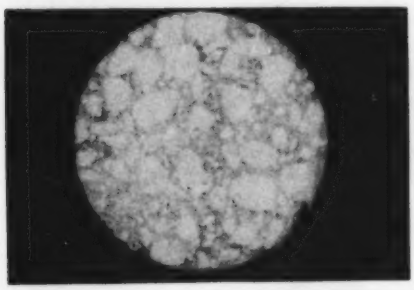


by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

These reports present the development and application of an analysis method for examining existing pavements for moisture accelerated distress. The logical step-by-step procedure can be used to evaluate the present condition of the pavement, determine what portion of the present distress, if any, can be related to moisture, and determine the factors involved. The procedure also indicates the potential for moisture accelerated distress to continue developing, and provides information on maintenance strategies best suited to halting or reducing the rate of moisture accelerated distress.

Limited copies of the reports are available from the Pavement Division, HNR-20, Federal Highway Administration, Washington, D.C. 20590. The reports also are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 82 181728 and PB 82 181736).

Mixing Efficiency of Recycled Asphalt Paving Mixtures, Report No. FHWA/RD-81/174



by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

This report covers an extensive evaluation of techniques for measuring the degree of mixing during the recycling of old asphalt pavements. The practice of using small amounts of rejuvenating or recycling agents is coupled with the problem of quality control. No suitable method exists for detecting how well the recycling agent (or, in some cases, virgin asphalt) mixes with the aged pavement materials. Usual quality control tests, such as extracting and measuring the binder content and properties, are not appropriate because these tests mask the presence of recycling agents and extent of mixing.

The project described in this report was to develop a test method that could be conducted in the field with a minimum of equipment and training. Among the more traditional tests, the resilient modulus (M_R) was found to be most suitable for physical testing of the recycled mixtures. This method could determine the relative quantity of recycling agent used because it is sensitive to small changes. However, as a quick test for measuring the efficiency of mixing, this method showed little promise.

Dye chemistry was found to be best among the less traditional methods used by civil engineers. After investigating many variables, the dye print technique was optimized. A small amount of dye chemical is incorporated into the recycling agent and thereby combined in the complete mixture as it passes through the asphalt mixing plant. By placing a sawed face of a resulting asphalt concrete briquet against a chemically treated piece of fabric, a dye print showing spots where the dye chemical (and hence, recycling agent) is located in the mixture then can be developed. Differences of various mixing patterns are readily observed. The resulting dye prints can be evaluated visually or by using densitometer scanning and statistical analysis techniques.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 257155).

System for Inventorying Road Surface Topography (SIRST), Report No. FHWA/RD-82/062

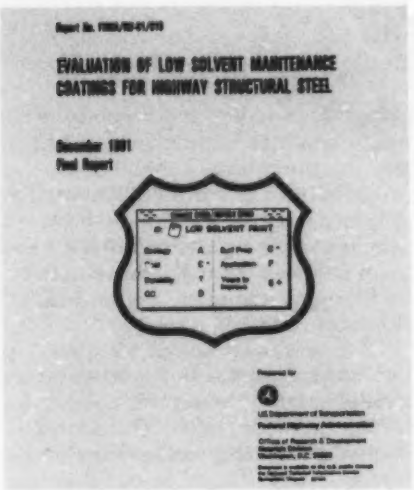
by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

An experimental trailer-mounted instrumentation system that surveys and records data on the roadway topography while being towed at normal highway speeds has been developed and tested. The system uses noncontacting electro-optical sensors to measure the relative height of the roadway surface along 12 selected paths spaced across a normal traffic lane. To compensate for trailer bounce, the vertical acceleration is measured and double integrated. Data on the cross slope and longitudinal slope of the surface and the direction of travel are obtained from a gyro-type inertial reference unit mounted on the instrumentation trailer. At 0.3 or 0.6 m (1- or 2-ft) intervals along the roadway (depending on the speed), a solid-state data acquisition system samples the outputs from each height sensor, the double integrated accelerometer signal, and the roll and pitch signals from the inertial reference system. These data are digitized and recorded on a digital cassette-type magnetic tape recorder. The data can be processed to provide the longitudinal profiles, cross slopes and ruts, or topographic maps. The vertical resolution is 0.5 mm (0.02 in); slope measurement accuracy is 0.5 degree.

Further evaluation is needed to establish performance under dynamic conditions and the correlation of the data on roadway surface topography with that of other measurement techniques.

Limited copies of the report are available from the Pavement Division, HNR-20, Federal Highway Administration, Washington, D.C. 20590. The report is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 83 104018).

Evaluation of Low-Solvent Maintenance Coatings for Highway Structural Steel, Report No. FHWA/RD-81/019



by FHWA Office of Engineering and Highway Operations R&D, Materials Technology and Chemistry Division

With increased restrictions on lead- and chromate-containing primers and the amount of organic solvents allowed in maintenance coatings, there is a great need to develop and evaluate suitable alternatives. The coatings industry has concentrated its major research efforts to meet these requirements.

This report summarizes the state of the art regarding regulations, new technology, impact upon structural steel painting practices, and recommendations. The most promising technologies include water-borne solutions and latices as well as reformulations with chlorinated solvents for mild and moderate environments, and with water-thinned zinc-rich paints and water-borne and high-solid epoxies for more severe environments.

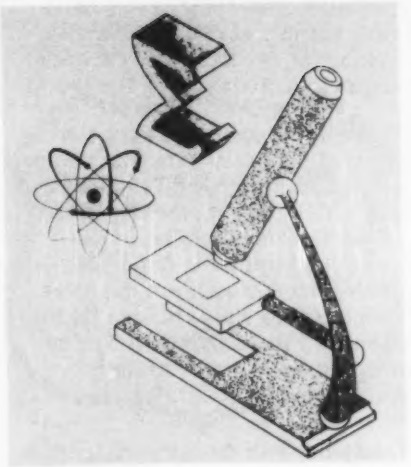
Although new technology is rapidly emerging, there is still no viable, safe, and practical low-solvent alternative now available for use on structural steel in most environments. It was concluded that at least 2 years are required before low-solvent coatings can be proven for use in mild environments, 5 years for moderate environments, and longer for severe, heavy-duty exposures. Procurement of low-solvent bridge paints and painting will require adoption of performance criteria, coordinated highway coatings evaluations, and recognition of the concept of zones of defense. Higher costs may be expected in more complicated paints, alternate surface preparation, more difficult application, closer inspection, and probably shorter painting cycles.

Limited copies of the report are available from the Materials Technology and Chemistry Division, HNR-40, Federal Highway Administration, Washington, D.C. 20590.

Recycling Agents for Recycled Bituminous Binders, Report No. FHWA/RD-82/010

by FHWA Office of Engineering and Highway Operations R&D, Materials Technology and Chemistry Division

This report describes a comprehensive evaluation of recycling agents and aged asphalt binders. Salvaged asphalt treated pavement materials were obtained, analyzed, and combined with recycling agents. Laboratory tests were performed on the field aged mixtures, field aged



asphalts, recycling agents, aged asphalt-recycled agent blends, and recycled mixtures. Results from these tests suggest that recycling agents can restore aged asphalts to desired consistency levels and can be used to produce recycled mixtures with acceptable properties. However, the type of recycling agent and the nature of the aged asphalts will determine the temperature susceptibility of the blended binder.

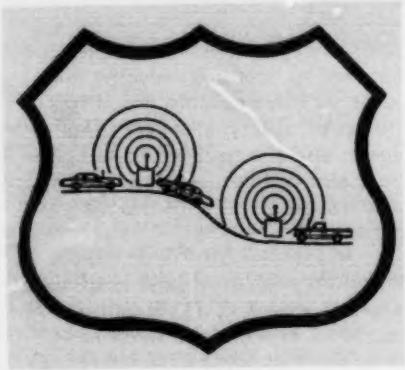
Potential problems exist with aged asphalt-recycling agent compatibility. Tests and criteria need to be developed to more accurately recognize such problems. In the interim, a laboratory oven aging test conducted on the aged asphalt-recycling agent blend is suggested for use.

Recycled mixture properties can be adjusted by controlling the amount of recycling agent added. The properties of recycled mixtures are dependent upon the method and temperature of sample preparation. The blending of the recycling agent with the aged asphalt is both time and temperature dependent.

Pavement performance has been predicted for recycling agents and a method for the design of recycled mixtures is contained in the report.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 197856). Limited copies of an Executive Summary, Report No. FHWA/RD-82/122, are available from the Materials Technology and Chemistry Division, HNR-40, Federal Highway Administration, Washington, D.C. 20590.

Feasibility and Concept Selection of a Safety Hazard Advance Warning System (SHAWS), Report No. FHWA/RD-81/123

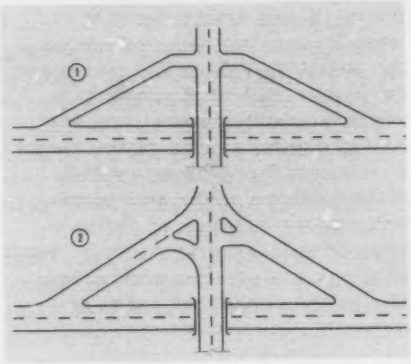


by FHWA Office of Safety and Traffic Operations R&D, Systems Technology Division

This report documents a study to investigate the feasibility of providing a Safety Hazard Advance Warning System (SHAWS) using low powered radio transmitters to warn motorists of potential hazards such as hidden intersections and moving maintenance operations. The system would transmit warnings to approaching vehicles by a simple audio and/or visual display. The system could be deployed on rural and urban secondary roads where hills, curves, vegetation, and other physical features hinder a driver's view of traffic and roadway hazards.

Limited copies of the report are available from the Systems Technology Division, HSR-10, Federal Highway Administration, Washington, D.C. 20590.

Procedures and Guidelines for Rehabilitation of Existing Freeway-Arterial Highway Interchanges, Vols. I-IV, Report Nos. FHWA/RD-81/103-106



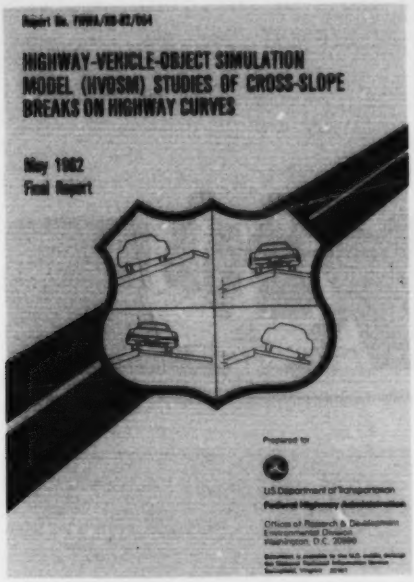
by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

During the past 40 years, the United States has constructed an extensive system of multilane, limited-access freeways. Freeway-arterial interchanges have been constructed at intervals to provide access from the conventional highway system to the freeway system. "Interchange rehabilitation" is defined as any construction or maintenance project intended to improve traffic operations or safety at an interchange through geometric design modifications.

These reports describe recommended interchange rehabilitation project design procedures including identification of interchanges with traffic operational or safety problems, identification of specific deficiencies through engineering studies, identification of improvement alternatives, quantification of the effects of improvement alternatives, evaluation and selection of the best alternatives, and implementation and evaluation of the improvement project.

Volume I, Executive Summary, gives a brief overview of the project objectives and results. Volume II, Design Procedures for Rehabilitation of Freeway-Arterial Interchanges, presents the procedures and guidelines recommended for use in interchange rehabilitation projects, and Volume III, Evaluation of Interchange Rehabilitation Projects, presents evaluations of 40 such projects recently constructed by highway agencies. Volume IV is the final research report.

Limited copies of the reports are available from the Safety and Design Division, HSR-20, Federal Highway Administration, Washington, D.C. 20590 .


HIGHWAY-VEHICLE-OBJECT SIMULATION MODEL (HVOSM) STUDIES OF CROSS-SLOPE BREAKS ON HIGHWAY CURVES
May 1982
Final Report
Prepared for
U.S. Department of Transportation
Federal Highway Administration

Highway-Vehicle Object Simulation Model (HVOSM) Studies of Cross Slope Breaks on Highway Curves, Report No. FHWA/RD-82/054

by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

The research described in this report was conducted to investigate the operational effects of cross slope breaks on highway curves. These breaks are created by the superelevation of the traveled way and the adverse shoulder slope. HVOSM simulation studies were performed on a variety of break designs to test the effects of curvature, speed, and vehicle path on vehicle operations.

The study findings revealed the importance of shoulder slope and width in designing the shoulder to accommodate vehicular recoveries on the outside of curves. Recommendations regarding design of cross slope breaks, including treatments for special situations such as narrow shoulders, high superelevation, and rehabilitation of projects, were derived from the research findings.

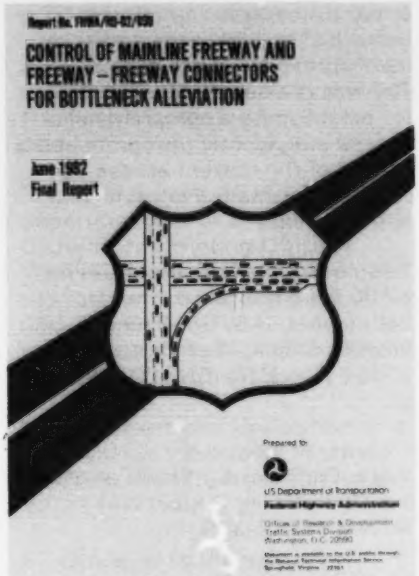
Limited copies of the report are available from the Safety and Design Division, HSR-20, Federal Highway Administration, Washington, D.C. 20590.

Control of Mainline Freeway and Freeway-Freeway Connectors for Bottleneck Alleviation, Report No. FHWA/RD-82/030

by FHWA Office of Safety and Traffic Operations R&D, Urban Traffic Management Division

This is the final report on a study that examined the feasibility of metering freeway connectors and mainline sections to improve traffic flow at bottlenecks downstream of the metering locations. The report presents guidelines that will enable operating agencies to determine the appropriateness of such control.

The principal finding in the study was that connector metering should be used only when ramp metering is not feasible or is insufficient to maintain uncongested traffic flow through a bottleneck location.


CONTROL OF MAINLINE FREEWAY AND FREEWAY – FREEWAY CONNECTORS FOR BOTTLENECK ALLEVIATION
June 1982
Final Report
Prepared for
U.S. Department of Transportation
Federal Highway Administration

Limited copies of the report are available from the Urban Traffic Management Division, HSR-40, Federal Highway Administration, Washington, D.C. 20590.

Measures of Effectiveness for TSM Strategies, Report No. FHWA/RD-81/177

by FHWA Office of Safety and Traffic Operations R&D, Urban Traffic Management Division

This report is the second and final report resulting from the study "Measures of Effectiveness for Multimodal Urban Traffic Management." The objectives of the study were to develop a comprehensive set of goals and objectives for transportation system management (TSM) strategies, to derive measures of effectiveness for determining the degree to which each objective was achieved, to develop a classification scheme for TSM strategies, and to identify and present data collection and analysis methods for the evaluation of TSM strategies.

This volume documents the research results and describes the study methodology. An earlier report, FHWA/RD-79/113, presented a summary of the study as a guide for practicing engineers and planners involved in developing and evaluating urban area TSM plans.

Limited copies of the reports are available from the Urban Traffic Management Division, HSR-40, Federal Highway Administration, Washington, D.C. 20590.

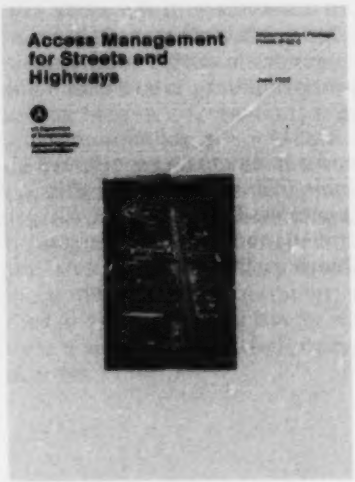
Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items that have been recently completed by State and Federal highway units in cooperation with the Office of Implementation, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies.

U.S. Department of Transportation
Federal Highway Administration
Office of Implementation (HRT-1)
Washington, D.C. 20590

Items from the Office of Implementation can be obtained by including a self-addressed mailing label with the request.

Access Management for Streets and Highways, Report No. FHWA-IP-82-3



by Office of Implementation

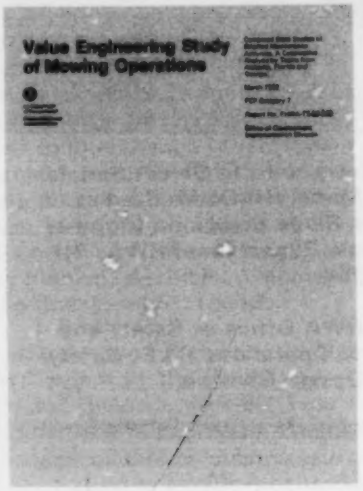
Access management is an effective technique for reducing traffic conflicts involving driveways and intersections. Most highway agencies have a comprehensive access management policy, but the effectiveness of current practices varies widely. This report was developed to further promote and encourage effective access management techniques, and provides design details and traffic operation methods for reducing the frequency and severity of traffic accidents at driveways. The report also provides guidance for establishing a comprehensive access management program and a review of the current access policies in Wisconsin, Pennsylvania, and Colorado.

This report may be purchased for $7.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00248-5).

Value Engineering Study of Mowing Operations, Report No. FHWA-TS-82-209

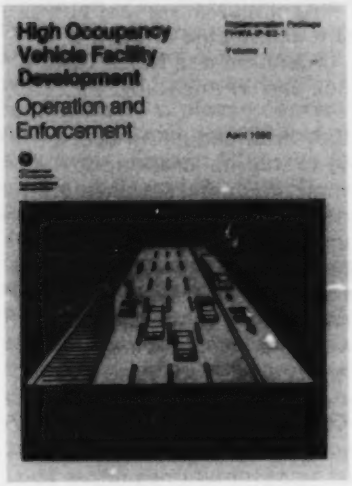
by Office of Implementation

This report is the 11th in a series on Optimizing Maintenance Activities and summarizes the results of a cooperative Value Engineering Study of Mowing Operations. The study was conducted by teams of maintenance and operations engineers from Alabama, Florida, and Georgia who applied value engineering techniques to both chemical and mechanical mowing operations.



The report includes specific recommendations on equipment combinations, use of herbicides, and establishing and enforcing a standard mowing height policy. By implementing these recommendations, the three participating States expect an estimated annual savings of $600,000.

Limited copies of the report are available from the Office of Implementation. The report is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 263872).



High Occupancy Vehicle Facility Development, Operation and Enforcement, Vols. I and II, Report No. FHWA-IP-82-1

by Office of Implementation

Priority treatment for high occupancy vehicle (HOV) projects was a direct result of energy shortages and escalating fuel prices. Numerous projects on HOV's have been implemented and evaluated. This report presents summaries of HOV project implementation experience and provides guidance on the planning, design, operation, and enforcement of HOV facilities.

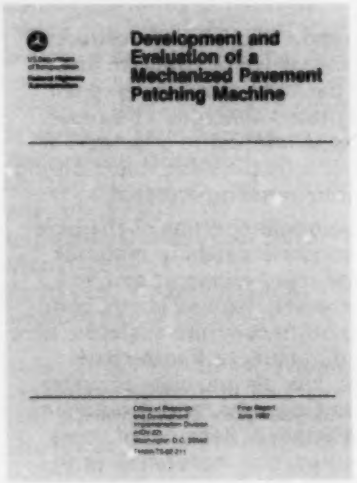
Volume I describes the need for HOV projects and depicts various HOV treatments. Volume II is an appendix that contains complementary materials for use with the HOV Treatment Selection Procedure detailed in Volume I.

The reports are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Volume I may be purchased for $8 (Stock No. 050-001-00247-1) and Volume II may be purchased for $5.50 (Stock No. 050-001-00249-3).

Development and Evaluation of a Mechanized Pavement Patching Machine, Report No. FHWA-TS-82-211

by Office of Implementation

This report presents the results of an evaluation of state-of-the-art pavement patching equipment. The evaluation was based on literature reviews and interviews with State highway department personnel.



The Perma-Patch Machine was found to meet the requirements for a fully mechanized pothole patcher.

The report also includes the results of field evaluations of the Perma-Patch Machine, which is a prototype device. Although the prototype equipment experienced some mechanical difficulties, the patch durability was very good and there were no failures in the patches placed during the study.

Limited copies of the report are available from the Office of Implementation. The report is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 262437).

Polymer Concrete Patching Manual, Report No. FHWA-IP-82-10

by Office of Implementation

This report describes procedures for using polymer concrete as a rapid patching material to repair deteriorated concrete. The report will be of interest to engineers in need of a long-lasting, rapid-curing concrete patching material.

The unique properties of the polymer concrete patching material include rapid curing at ambient temperature, high strength, good adhesion to concrete surfaces, long term durability to freeze-thaw cycles, low permeability to water and deicing salts, and good chemical resistance. Because of these properties, this material is especially suitable for use at sites where traffic conditions restrict closing for repair work.

Limited copies of the report are available from the Office of Implementation.

Transverse Cracking of Asphalt Pavement, Report No. FHWA-TS-82-205

by Office of Implementation

Through the years, there have been much research and many reports on elimination and reduction of transverse cracking of asphalt pavements. Most of the studies indicated that transverse cracking can be reduced through mix design procedures and asphalt grade and quality controls, but followup reports on the success of these procedures are not available.

At the September 1981 pavement management study meeting in Omaha, Nebr., representatives from Iowa, Kansas, and Nebraska recognized the need for an indepth engineering study of thermal cracking of bituminous pavement and agreed to participate in such a study. Oklahoma and North Dakota also took part in the study.

The study analyzed all functions relating to thermal cracking to determine how different uses of preventive materials, mix design measures, maintenance repairs, and design of bituminous pavements and overlays contributed to the problem and determined what improvements could be made in these procedures to reduce thermal cracking. This report presents the study approach, results, and recommendations. It should be of interest to pavement designers and maintenance engineers concerned with asphalt pavement performance.

Limited copies of the report are available from the Office of Implementation.

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research, Development, and Technology. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R)—Performing State Highway or Transportation Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1N: Safety of Bicyclists, Moped Operators, and Pedestrians

Title: Methods of Increasing Pedestrian Safety at Right Turn on Red Intersections. (FCP No. 31N1052)
Objective: Identify and field test engineering approaches to increase pedestrian safety at right turn on red intersections. Examine guidelines for the prohibition of right turn on red.
Performing Organization: Goodell Grivas, Inc., Southfield, Mich. 48075
Expected Completion Date: September 1984
Estimated Cost: $161,856 (FHWA Administrative Contract)

FCP Project 1P: Visual Guidance for Night Driving

Title: Reflective Characteristics of Roadway Pavements During Wet Weather. (FCP No. 31P2012)
Objective: Determine the directional reflective characteristics of common pavements during wet weather and develop a design procedure that will facilitate the consideration of wet weather in the design of roadway lighting systems.
Performing Organization: Ketron, Inc., Wayne, Pa. 19087
Expected Completion Date: August 1984
Estimated Cost: $226,287 (FHWA Administrative Contract)

FCP Project 1S: Compatibility of Highway and Vehicle Standards with Driver Characteristics

Title: Vehicle Characteristics Affecting Highway Design. (FCP No. 31S1062)
Objective: Identify the highway geometric design and traffic control criteria that are affected by vehicle characteristics. Determine the relationship of these vehicle characteristics to geometric design and traffic operations criteria. Develop trends and distributions of the vehicle characteristics that affect current criteria. Determine the sensitivity of these criteria to changes in vehicle characteristics.
Performing Organization: Wagner-McGee Associates, Inc., Alexandria, Va. 22304
Expected Completion Date: March 1984
Estimated Cost: $135,500 (FHWA Administrative Contract)

Title: Side Friction for Superelevation on Horizontal Curves. (FCP No. 31S2042)
Objective: Perform analytical evaluation of the forces on each wheel of a vehicle. Using this information, evaluate criteria for superelevation using several specific conditions, such as front-wheel drive, wet pavement, etc. Perform field tests to validate the analytical assessment.
Performing Organization: HSRI, University of Michigan, Lansing, Mich. 48109
Expected Completion Date: June 1985
Estimated Cost: $150,000 (FHWA Administrative Contract)

FCP Project 1U: Safety Aspects of Increased Size and Weight of Heavy Vehicles

Title: Truck Stopping Sight Distance Requirements. (FCP No. 31U2072)
Objective: Determine the stopping sight distance requirements of the existing truck population and how well the stopping sight distances provided by American Association of State Highway and Transportation Officials design standards meet these requirements.
Performing Organization: Automated Sciences Group, Inc., Silver Spring, Md. 20910
Expected Completion Date: August 1983
Estimated Cost: $100,000 (FHWA Administrative Contract)

FCP Project 1X: Highway Safety Program Effectiveness Evaluation

Title: Exposure Measures for Evaluating Highway Safety. (FCP No. 31X1052)
Objective: Develop appropriate exposure measures for various highway geometric and traffic conditions. Identify data collection techniques for each exposure method including sampling, cost, and reliability.
Performing Organization: University of North Carolina, Chapel Hill, N.C. 27514
Expected Completion Date: September 1983
Estimated Cost: $167,250 (FHWA Administrative Contract)

FCP Project 1Y: Traffic Management in Construction and Maintenance Zones

Title: Development of a Low-Cost, Low-Maintenance Channelizing Device. (FCP No. 31Y1154)
Objective: Develop a set of functional requirements for channelizing devices that would be used to separate traffic in a two-lane, two-way operation (TLTWO).
Performing Organization: Russel M. Lewis, Annandale, Va. 22003
Expected Completion Date: September 1983
Estimated Cost: $53,640 (FHWA Administrative Contract)

FCP Category 2—Reduce Congestion and Improve Energy Efficiency

FCP Project 2L: Detection and Communications for Traffic Systems

Title: Evaluation of Inductive Loop Configurations. (FCP No. 42L1072)
Objective: Document the operational characteristics and reliability of performance of inductive loop configurations which are currently used in Florida or other States for the detection of all types of vehicles on the highway.
Performing Organization: Florida Department of Transportation, Gainesville, Fla. 32602
Expected Completion Date: January 1984
Estimated Cost: $66,000 (HP&R)

FCP Category 3—Environmental Considerations in Highway Design, Location, Construction, and Operations

FCP Project 3E: Reduction of Environmental Hazards to Water Resources Due to the Highway System

Title: Management Practices for Mitigation of Highway Stormwater Runoff. (FCP No. 33E3302)
Objective: Synthesize and evaluate current stormwater and non-point source runoff management practices. Identify practical, effective, implementable mitigation measures to reduce or eliminate the impact from highway stormwater runoff. Develop guidelines for implementation of highway stormwater runoff mitigation measures and management practices.
Performing Organization: Versar, Inc., Springfield, Va. 22151
Expected Completion Date: February 1984
Estimated Cost: $148,479 (FHWA Administrative Contract)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4K: Cost-Effective Rigid Concrete Construction and Rehabilitation in Adverse Environments

Title: Long Term Evaluation of Bridge Decks. (FCP No. 44K2344)
Objective: Observe bridge decks to determine performance characteristics of decks built with conventional portland cement concrete

and uncoated steel reinforcements in a chloride-intensive environment. Perform visual observations, chain drags, chloride contents, and half-cell potentials.
Performing Organization: New York State Department of Transportation, Albany, N.Y. 12232
Expected Completion Date: December 1992
Estimated Cost: $147,800 (HP&R)

Title: Installation of Cathodic Protection System. (FCP No. 34K3003)
Objective: Select an appropriate bridge and select, design, install, monitor, and evaluate a state-of-the-art cathodic protection system.
Performing Organization: Pennsylvania Department of Transportation, Harrisburg, Pa. 17120
Expected Completion Date: May 1986
Estimated Cost: $60,000 (FHWA Administrative Contract)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5A: Improved Protection Against Natural Hazards of Earthquake and Wind

Title: Seismic Design Guidance. (FCP No. 35A1902)
Objective: Develop general guidance for the earthquake design of transportation structures. Based on post observed damage, develop a seismic zone map of the United States depicting the regions where ground motion can adversely affect transportation structure response.
Performing Organization: Computech Engineering Services, Berkeley, Calif. 94705
Expected Completion Date: September 1983
Estimated Cost: $25,225 (FHWA Administrative Contract)

Title: Large-Scale Quasi-Dynamic Bridge Column Testing. (FCP No. 35A2618)
Objective: Conduct tests of full-scale and reduced-scale reinforced concrete bridge columns, designed by recently developed seismic design guidelines, to determine (1) effects of scaling factor on the interpretation of results obtained from small scale testing, (2) column performance and ductility, and (3) performance of repaired columns.
Performing Organization: National Science Foundation, Washington, D.C. 20550
Expected Completion Date: May 1985
Estimated Cost: $40,000 (FHWA Administrative Contract)

FCP Project 5K: New Bridge Design Concepts

Title: Techniques for Measuring Existing Long Term Stresses in Prestressed Concrete Bridges. (FCP No. 35K3162)
Objective: Develop techniques for measuring long term (existing) stresses in prestressed concrete bridges by (1) a state-of-the-art survey, (2) analytical studies, (3) laboratory studies, and (4) field studies. Develop a manual of operations for using the techniques.
Performing Organization: Construction Technology Laboratory, Skokie, Ill. 60077
Expected Completion Date: June 1985
Estimated Cost: $318,100 (FHWA Administrative Contract)

FCP Category 6—Improved Technology for Highway Construction

FCP Project 6E: Rigid Pavement Systems Design

Title: Design to Prevent Pumping in Rigid Pavement. (FCP No. 36E2043)
Objective: Develop improved rigid pavement support in terms of erosion resistance to withstand excess water pressure, permeability, and/or limiting deflection. Establish trade-off criteria among subbase support, slab thickness, load transfer, reduced water infiltration, and subsurface drainage as design tool to prevent pumping. Develop procedures for incorporating a consideration of pumping into the overall design of rigid pavements.
Performing Organization: Purdue Research Foundation, West Lafayette, Ind. 47907
Expected Completion Date: August 1984
Estimated Cost: $75,000 (FHWA Administrative Contract)

FCP Project 6G: Performance Related Quality Assurance Specification for Highway Construction

Title: Cost Effectiveness of Current Sampling and Testing Programs for Paving Construction and Materials. (FCP No. 36G3014)
Objective: Provide State agencies with means of priorities among quality control tests and for optimizing sampling frequencies for each test. Establish cost effectiveness of tests for bituminous binders and mixtures, hydraulic

cements and concretes, and soils and soil aggregates. Base cost effectiveness assessment on available data relating test results to performance (pavement serviceability) and on other factors such as the initial cost and quantity of the product, cost of the testing, failure rates and variabilities typically encountered with the material, and criticality of performance.
Performing Organization: Brent Rauhut Engineering, Inc., Austin, Tex. 78758
Expected Completion Date: May 1984
Estimated Cost: $110,000 (FHWA Administrative Contract)

FCP Category 7—Improved Technology for Maintenance

FCP Project 7A: Physical Maintenance

Title: Rapid Repair of Wet Asphalt. (FCP No. 47A1284)
Objective: Identify and field test materials and work methods which will yield a long lasting, economical, wet weather patch for asphalt concrete pavements.
Performing Organization: University of Texas, Austin, Tex. 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: July 1985
Estimated Cost: $100,000 (HP&R)

Title: Pavement Marking Removal. (FCP No. 47A4164)
Objective: Investigate pavement marking removal methods for effectiveness and efficiency. Document methods used, contract conditions, and results achieved. Introduce variations in procedures when it appears improved results may be achieved.
Performing Organization: New York State Department of Transportation, Albany, N.Y. 12232
Expected Completion Date: January 1985
Estimated Cost: $90,000 (HP&R)

FCP Category 0—Other New Studies

Title: The Expanded Montana Asphalt Quality Study Using High Pressure Liquid Chromatography (HPLC). (FCP No. 40M3752)
Objective: Determine the validity of the correlation of molecular size distribution of asphalts (determined by an HPLC technique) with pavement performance of normal and recycled asphaltic pavements. Develop guidelines and implement the use of the HPLC method in asphalt pavements.
Performing Organization: Montana State University, Bozeman, Mont. 59717
Funding Agency: Montana Department of Highways
Expected Completion Date: April 1984
Estimated Cost: $272,511 (HP&R)

Dr. Edward T. Harrigan (left) and Mr. Howard J. Lentz (right) with Mr. Edwin M. Wood, Associate Administrator, Offices of Research, Development, and Technology.

Edward T. Harrigan and Howard J. Lentz Receive Awards

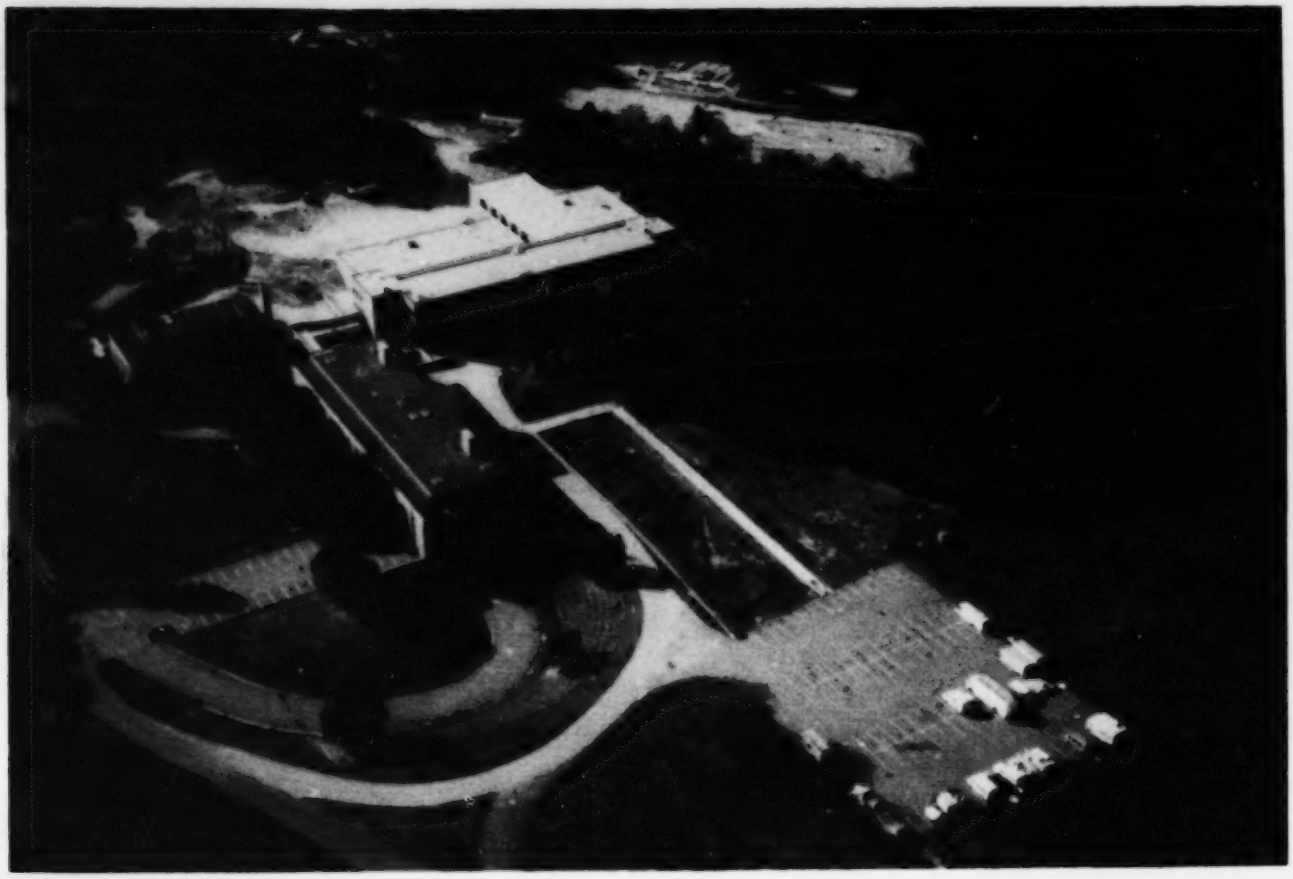
Dr. Edward T. Harrigan and Mr. Howard J. Lentz were the recipients of the 1982 award in the annual outstanding paper competition held among the employees of the Federal Highway Administration (FHWA) Offices of Research, Development, and Technology. This award covers the documentation of any technical accomplishment, which may be a publication, technical paper, report, or package; an innovative engineering concept; an instrumentation system; test procedure; new specification; mathematical model; or unique computer program. Each eligible candidate is judged on excellence, creativity, and contribution to the highway community, general public, and FHWA.

Messrs. Harrigan and Lentz received their awards for their research paper, "Laboratory Evaluation of Sulphlex-233, Binder Properties and Mix Design."

Edward T. Harrigan is a research chemist in the Materials Technology and Chemistry Division, Office of Engineering and Highway Operations Research and Development (R&D). Before joining FHWA in 1974, he was a weapons test project officer for the Air Force Systems Command. He is currently technical manager for contract studies in several areas of materials research, including delineation, alternative binder materials, and deicing chemicals.

H. J. (Bud) Lentz is a supervisory materials engineering technician in the Pavement Division of the Office of Engineering and Highway Operations R&D. He supervises the bituminous mixtures research laboratory. Before joining FHWA in 1969, he supervised Amoco's paving and roofing asphalt research and technical service laboratory in Baltimore, Md.

★U.S. Government Printing Office: 1982—381-783/201



Expanded Research Facility

The expanded research facility at the Fairbank Highway Research Station in McLean, Va., is nearing completion. The new facility will provide additional laboratory, office, and support space, centralizing the Offices of Research, Development, and Technology, which are presently located in both Washington, D.C., and McLean. Dedication ceremonies for the new facility will be held in the spring.

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Intersection Control and Accident Experience in Rural Michigan

Observations of Full-Scale Pile Group Performance

Public Roads

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